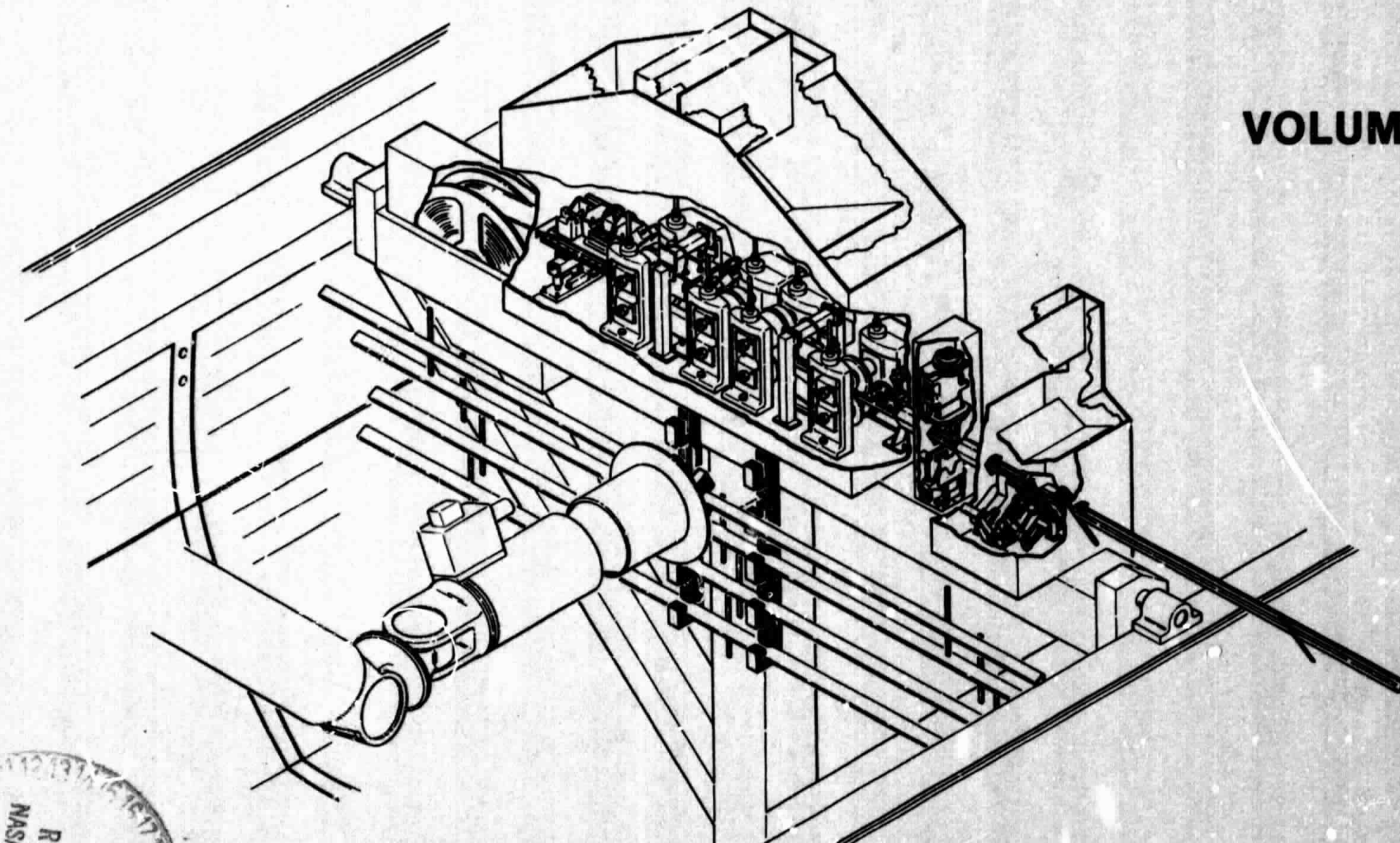
COMPOSITE BEAM CAP FABRICATOR FLIGHT EXPERIMENT DEFINITION STUDY

VOLUME I



Final Report — July 30, 1982

GRUMMAN AEROSPACE CORPORATION

(NASA-CR-170688) COMPOSITE BEAM CAP FABRICATOR EXPERIMENT DEFINITION STUDY, VOLUME 1 Final Report (Grumman Aerospace Corp.) 151 p HC A08/MF A01 CSCL 13H

N83-14305

Unclas
G3/31 01672

FOREWORD

This final report was prepared by Grumman Aerospace Corporation for NASA Marshall Space Flight Center in fulfillment of Modification No. 26 of Contract NAS8-32472. It consists of two volumes:

- Volume I – Final Report
- Volume II – Preliminary Flight Mission Plan

The study results were developed during the period 15 December 1981 to 30 July 1982. Reviews were conducted at NASA MSFC at the orientation meeting on 15 December 1981, at the mid-term on 9 April 1982 and at the final review on 30 July 1982. Funding for this study was $59,205.

The study was performed for the Advanced Systems Office of MSFC (Program Development Directorate) which is under the direction of Herman Gierow. Special acknowledgment is accorded the NASA MSFC COR, Erich Engler, who provided guidance and close communication throughout the study.

The Grumman Aerospace Corporation study manager was Grahme Fischer. For further information, contact:

- Eirch E. Engler, EP-13 Building 4610, NASA George C. Marshall Space Flight Center, Huntsville, Alabama 35812
- Grahme Fischer, A09-25, Grumman Aerospace Corporation, Bethpage, New York 11714.

OUTLINE OF TOPICS

- INTRODUCTION & CBCF FLIGHT READINESS
- FLIGHT EXPERIMENT GOALS & TECHNICAL JUSTIFICATION
- MAJOR SYSTEMS OF FLIGHT EXPERIMENT
  - – DETAILED PRELIMINARY DESIGNS
- CONSIDERATIONS ON LOCATION OF FLIGHT EXPERIMENT WITHIN PAYLOAD BAY
- FLIGHT EXPERIMENT CONFIGURATIONS
- FABRICATION & MISSION TIMELINES
- HAZARD ANALYSIS
- POTENTIAL FLIGHTS & CONSTRAINTS ON FLIGHT OPPORTUNITY
- PROGRAMMATICS & COSTS
- RECOMMENDATIONS & CONCLUSIONS

GRUMMAN

1230-052B

EXISTING COMPOSITE BEAM CAP FABRICATOR

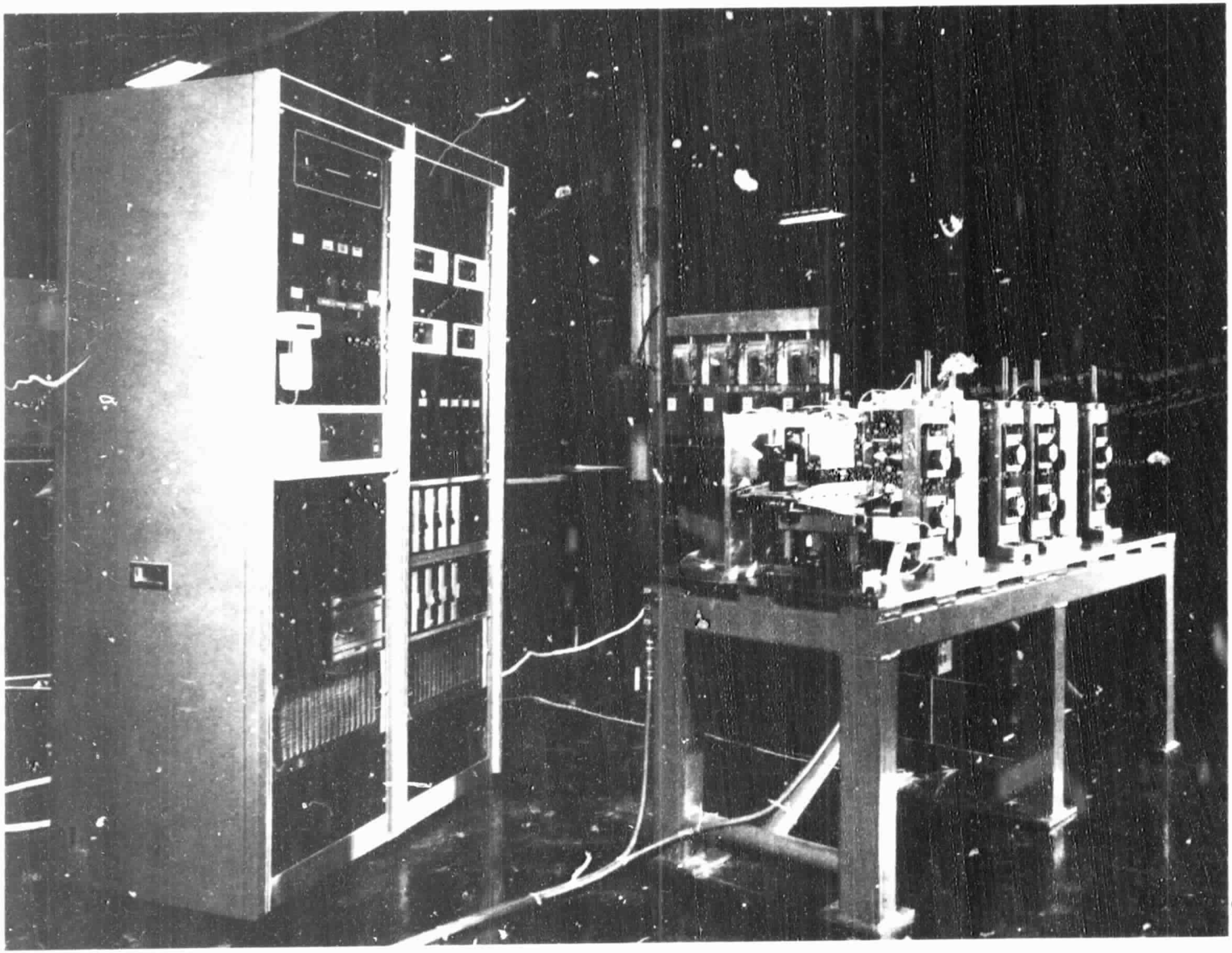
INTRODUCTION

The Composite Beam Cap Fabricator (CBCF) is part of a family of machines that have been designed to develop and augment the technology of space fabrication – the automatic production of basic structural members in space. Prior to the construction of the CBCF, all space fabrication machinery had manufactured aluminum structural members (e.g., the Aluminum Beam Builder). The CBCF roll forms a flat strip of Graphite/Thermoplastic into the open diamond shape shown on the following page.

The facing page shows the major components of the CBCF. The input end of the rolling mill is shown in the right foreground. The mill weighs approximately 1400 pounds and its size is approximately 6 feet by 2 feet by 2 feet. The left foreground of the photograph shows the controller units which house the microprocessor, controls and displays. The center background shows the power regulators for the quartz heating lamps (which are used to soften the graphite/thermoplastic prior to roll forming into a cap).

The CBCF was developed under a low cost, proof-of-concept type of contract. Consequently, all components are made of commercially available hardware. Neither weight nor volume constraints were considered during the development of this machine. For example, over 3/4 of the volume enclosed by the controller units is empty.

EXISTING COMPOSITE BEAM CAP FABRICATOR



GRUMMAN

1230-054B

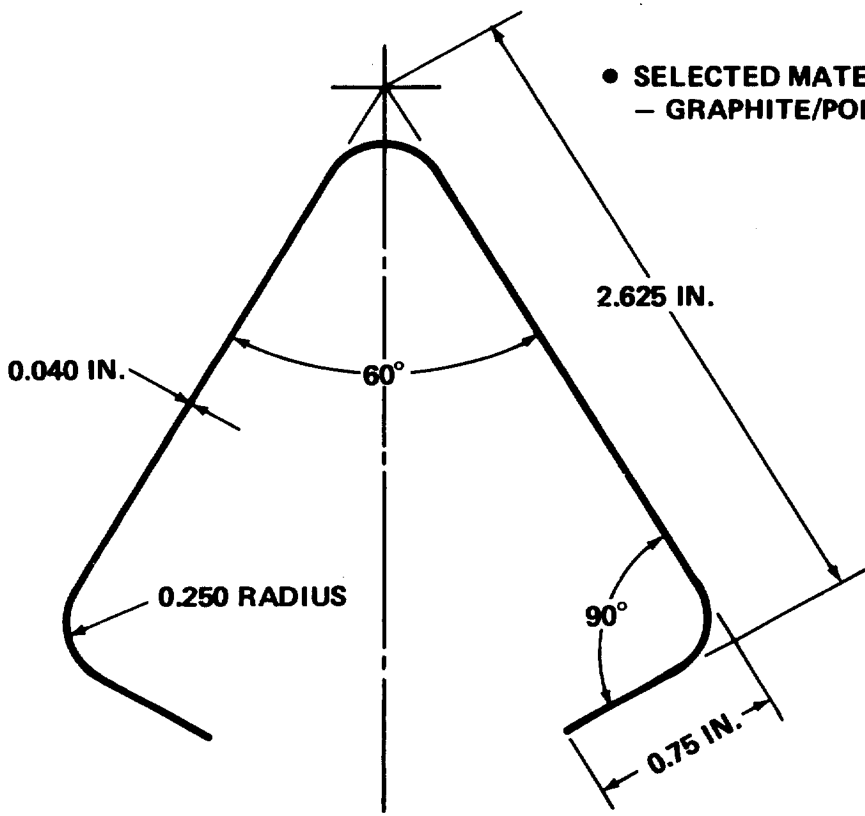
OUTPUT OF ROLL FORMING OPERATION

The cap shape produced by the CBCF roll forming operation is similar to the one produced by the Aluminum Beam Builder. However, at .040" thick, the composite cap is considerably thicker than its aluminum counterpart. This additional thickness is required by state-of-the-art composite materials technology.

Three different materials were successfully roll formed on the CBCF to the cap shape shown on the facing page: graphite/acryllic, graphite/polysulfone and graphite/polyethersulfone. Of these, graphite/polyethersulfone is preferred for a CBCF flight experiment since it is the more formable of the high temperature thermoplastics.

OUTPUT OF ROLL FORMING OPERATION

COMPOSITE BEAM CAP MEMBER CROSS-SECTION



- SELECTED MATERIAL
  - GRAPHITE/POLYETHERSULFONE

GRUMMAN

1230-024B

FLIGHT READINESS

The existing CBCF was examined from the point of view of its ability to successfully sustain the launch and space environments while attached to an Orbiter.

The entire electrical and electronic system of the ground demonstrator CBCF will probably have to be replaced for space flight. The electronic components rely on convective air cooling. None of the commercial components have been designed to survive the rigorous vibrations of a Shuttle launch. Also, fire resistant wiring is required for space. Although it is possible that some of the existing components may pass a rigorous screening and test program, it is not likely that many will be useable in space.

FLIGHT READINESS: ELECTRICAL DESIGN

- ALL COMPONENTS ARE COMMERCIAL GRADE
  - ADEQUATE TO DEMONSTRATE PROCESS FEASABILITY ON THE GROUND
  - NO SPACE QUALIFIED COMPONENTS
    - VIBRATION
    - THERMAL VACUUM
    - RADIATION
    - FIRE RESISTANCE

    CRITICAL CRITERIA WHICH WERE NOT CONSIDERED BY MANUFACTURER
- INEFFICIENT USERS OF SPATIAL VOLUME
  - MICROPROCESSOR
  - POWER CONDITIONING
- REPLACEMENT OF ENTIRE ELECTRICAL/ELECTRONIC SYSTEM IS REQUIRED
  - MICROPROCESSOR
  - POWER CONDITIONING
  - POWER DISTRIBUTION
  - SENSORS (PYROMETER, ENCODER)
  - DISPLAYS
  - MOTORS
  - WIRING

V82-0630-037P

FLIGHT READINESS: MECHANICAL DESIGN

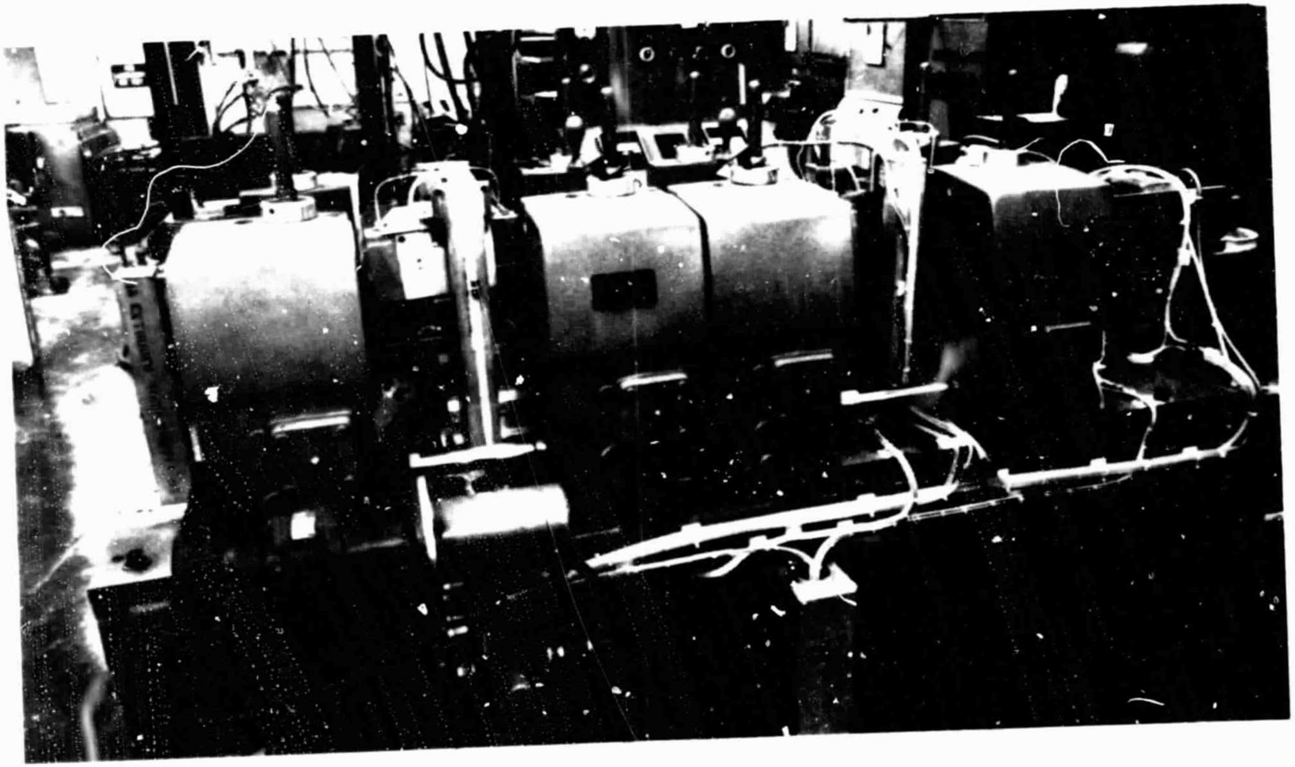
The existing CBCF relies on friction generated during bolt clamp up to maintain the position of several machine elements. These components have attachment slots to allow precise position adjustment. All components on the CBCF are attached either directly to the base plate or to other parts which are attached to tapped holes in the base plate. All attachments to the base plate use either nuts and bolts or screws. None of these attachments are self-locking. The severe vibrations of a Shuttle launch will preclude the use of all of these friction retention methods. Positive locking systems will be required for CBCF utilization in space.

Each of the four rolling mill housings contain several bearings and gear meshes. These, plus the rolling mill drive motor and speed reducer (left foreground of facing page photograph), will require lubrication systems that are effective in zero gravity.

FLIGHT READINESS: MECHANICAL DESIGN

SEVERAL AREAS REQUIRE REDESIGN FOR FLIGHT

- NON-LOCKING HARDWARE
  - NUTS & SCREWS (ALL ATTACHMENTS INTO BASEPLATE)
- CLAMP-UP FRICTION RETENTION SYSTEMS (HEATER SUPPORTS, PYROMETERS, PYROMETER SUPPORTS)
- LUBRICATION IN ZERO G (CHAIN DRIVE, BEARINGS, GEARS)



GRUMMAN

V82-0630-035P

EXPERIMENT LOADS FROM FLIGHT CONDITIONS

To determine the flight readiness of the CBCF, an assessment of the machine's ability to sustain the forces expected during launch, orbital operations and return to earth is necessary.

Maximum steady state load factors are listed in JSC 07700 and are repeated in Appendix A of this report (Tables 5 through 9). The maximum values of these load factors are shown on the facing page.

Maximum load factors for vibratory events during launch will require experimental evaluation to determine stiffness and damping characteristics of the major flight experiment components. These characteristics can then be applied to a coupled body transient analysis which will determine maximum vibration load factors. For early design efforts when the transient analysis data is unavailable, the recommendations on the bottom of the facing page are suggested.

EXPERIMENT LOADS FROM FLIGHT CONDITIONS

MAX STEADY STATE LOADS (ULTIMATE LOAD FACTORS)

EMERGENCY LANDING	$N_x = 4.5$ g	ORB BOOST	$N_x = -4.44$ g	QUASI STEADY STATE
	$N_y = \pm 1.5$ g	TAEM: YAW	$N_y = \pm 1.12$ g	
	$N_z = 4.5$ g	TAEM: ROLL	$N_z = 3.5$ g	

TRANSIENT FLIGHT EVENTS

- SIGNIFICANT ELASTIC RESPONSE (VIBRATION); ACCURATE ESTIMATE REQUIRES COUPLED TRANSIENT ANALYSIS PLUS VIBRATION TESTS
- METHOD OF JSC 07700, APPENDIX I-4
  - LONGERON LOAD ATTENUATION FACTORS BETWEEN 12 & 21:1

RECOMMENDATION OF GRUMMAN LOADS & DYNAMICS DEPARTMENT

- APPLY ±50 g (IN ANY DIRECTION) TO SMALL COMPONENTS (~ 100 LB)
- APPLY ± 100 g (IN ANY DIRECTION) TO VERY SMALL COMPONENTS (~ 1 LB)
- DESIGN EXPERIMENT SUPPORT STRUCTURE TO QUASI STEADY STATE LOADS
- SHOCK MOUNTING OF FLIGHT EXPERIMENT WON'T WORK
  - BROADBAND EXCITATION TOO DIFFICULT TO AVOID
  - LARGE EXPERIMENT DEFLECTIONS WILL RESULT

V82-0630-038P

STRENGTH SUMMARY OF EXISTING CBCF

Three different materials comprise the major structure of the CBCF: aluminum (6061T6) weldments to support quartz heaters, pyrometers and the str... ...ening stage, cast iron for the housings (stands) of the rolling mill, and low and medium carbon steel for shafts, base plate, gears, bolts, etc.

The aluminum parts are weakest at the welded regions. Consequently, only "as welded" properties are shown on the opposite page. The endurance limit (F_E) is for only one direction of load application ($R = 0$). That is, one cycle of load goes from zero load to max load to zero load. No stress reversal occurs. The weld stress concentration factor (K_F) is applied to tensile stress after a Mohr's Circle analysis.

The properties of the cast iron shown on the facing page represent a class of cast iron that was probably used for manufacturing the rolling mill housings. The material was described by Yoder as being a "high grade cast iron with a tensile yield strength of 40,000 psi". The general stress concentration factor (K_F) is applied to all tensile loads independently of the local radius or geometry. It results from the presence of graphite flakes within the cast iron.

STRENGTH SUMMARY OF EXISTING CBCF

- ALLOWABLE STRENGTHS

  – 6061T6 AS WELDED:
  $F_{TU} = 21{,}000$ PSI
  $F_{TY} = 13{,}000$ PSI
  $F_E = 4{,}200$ PSI FOR $\begin{cases} R = 0 \\ N = 10^7 \text{ CYCLES} \end{cases}$

  WELD STRESS CONCENTRATION FACTOR: $K_F = 2.5$

  – MALEABLE CAST IRON:
  TYPE 35018
  (= "HIGH GRADE CAST IRON $F_{TY} = 40{,}000$ PSI")
  $F_{TU} = 53{,}000$ PSI
  $F_{TY} = 35{,}000$ PSI
  $F_C = 220{,}000$ PSI
  $F_{SU} = 51{,}000$ PSI
  $F_E = 31{,}000$ PSI

  GENERAL STRESS CONCENTRATION FACTOR: $K_F = 1.25$

  – 1050 STEEL:
  ANNEALED $\begin{cases} F_{TY} = 43{,}000 \\ F_{TU} = 92{,}000 \end{cases}$

  FLAME HARDENED KEYWAY $F_{TU} > 180{,}000$ PSI
  KEYWAY STRESS CONCENTRATION FACTOR $K_F = 1.3$

  – HARDWARE:
  SOCKET HEAD SCREWS – STEEL $F_{TU} = 170{,}000$ PSI
  HEX HEAD BOLTS – AISI 1019 $F_{TU} = 58{,}000$ PSI
  DOWEL PINS – CASE HARDENED STEEL $F_{TU} > 180{,}000$ PSI

782-06-:0-039P

STATION 1 DETAILS: STRENGTH SUMMARY (CONTD)

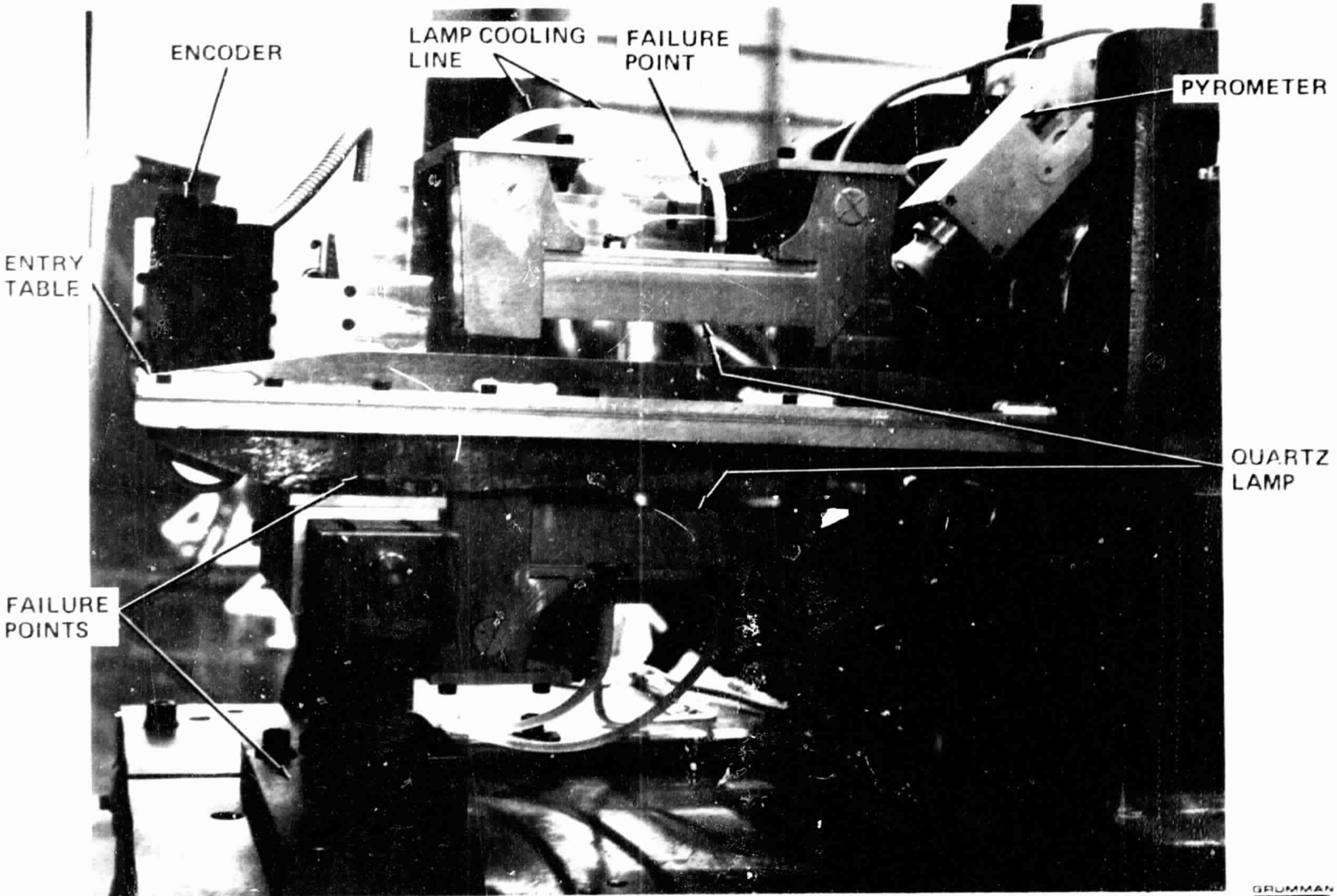
This view of the CBCF shows the entry table region at the input end. Upper and lower quartz lamps are used to heat both sides of the composite material just before roll forming. The lamp reflectors are water cooled during operation. The first pair of roll forming dies are on the right side. Part of the upper die is visible under the Pyrometer. The encoder is used to measure the length of material which has been roll formed.

Typical failure points (regions of likely failure under a ±50g vibratory load in any direction) are shown at 3 locations. The upper failure point occurs at the weld between vertical and horizontal plates that support the quartz lamps. The failure modes here (see case 3 on page 17) are fatigue failures in bending or torsion, depending upon which direction the maximum vibrations (loads) occur. In bending, the max tensile stress (from MC/I) times a weld stress concentration factor ($K_t f_b$ = 18000 psi) exceeds the allowable tensile yield stress (F_{TY}) but does not exceed the allowable tensile ultimate stress (F_{TU}). Consequently, only a relatively small number of cycles of this type of loading is expected before failure. Torsional loading at the upper failure point produces $K_f f_t$ = 9700 psi (after a Mohr's Circle analysis of shear stress) and reversed stress. This exceeds the endurance limit (4200 psi) for non-reversed stress by a large amount. Consequently fatigue failure is indicated on the following page.

The middle failure point on page 15 (case 2a on page 17) is a torsion failure of the welded region at the bottom of 2 vertical plates which support the entry table. Since the developed tensile stress ($f_t = f_s$ = 25900 psi) exceeds F_{TU} without any stress concentration, the part will break during the first cycle of load application. Consequently, the failure is termed "Static".

The lower failure point on page 15 (case 2b on page 17) occurs on any one of 3 vertical steel columns which are the catilever supports for the entry table. They develop a bending stress (f_b) of 85000 psi, which greatly exceeds the allowable yield stress of 43000 psi. The minimum amount of damage that might occur is extensive yielding. Since this would result in entry table misalignment, it constitutes failure. Probably, the columns will fail in fatigue.

STATION 1 DETAILS: STRENGTH SUMMARY (CONTD)



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

GRUMMAN

V82-0630-034P

STRENGTH SUMMARY OF EXISTING CBCF (CONTD)

UNDERSTRENGTH PARTS

On the facing page, "Static" implies a part failure will probably occur during the first few cycles of load application. Fatigue and Probable Fatigue imply several thousands of cycles of vibration are required to produce failure. For example, case 4b on the facing page generates a maximum tensile stress ($K_f f_t$) of 6900 psi, which exceeds the endurance limit of the material (4200 psi for R = 0). For 3 minutes of vibration at the parts resonant frequency of 230 Hz, over 40000 cycles of reversed stress are experienced. While it is not known that this number of cycles will produce failure of this material at these stress levels, it is clear that the margin of safety is not satisfactory. Consequently, this part is considered understrength at this weld.

STRENGTH SUMMARY OF EXISTING CBCF (CONTD)

UNDERSTRENGTH PARTS

- FAILURE LOAD IS ±50 g (IN ANY DIRECTION) VIBRATION AT THE PARTS 1ST RESONANT FREQUENCY

PART NAME	FAILURE LOCATION	TYPE LOADING	FAILURE TYPE
1) SPOOL MOUNTING BRACKET	a) WELD AT BASE OF "T" b) WELD AT STIFFENER & PLATE	BENDING TORSION	"STATIC": $K_f f_b > F_{TU}$ "STATIC": $K_f f_t > F_{TU}$
2) ENTRY TABLE ADAPTER	a) WELD AT VERTICAL COLUMN b) BASE OF LOWER BODY	TORSION BENDING	STATIC: $f_t > F_{TU}$ YIELDING: $f_b \approx F_{TU} \gg F_{TY}$
3) STATION 1 HEATER SUPPORT	WELD JOINING 2 PLATES	BENDING TORSION	FATIGUE: $K_f f_b > F_{TY}$ FATIGUE: $K_f f_t > F_E$
4) STATION 3 HEATER/PYROMETER SUPPORT	a) WELD AT COLUMN BASE b) WELD AT END OF MIDDLE BEAM	BENDING TORSION (≈40,000 CYCLES)	"STATIC": $K_f f_b > F_{TU}$ PROBABLE FATIGUE: $K_f f_t > F_E$
5) STATION 6 HEATER/PYROMETER SUPPORT	WELD AT COLUMN BASE	BENDING	PROBABLE FATIGUE: $F_{TY} \approx K_f f_b > F_E$
6) STATION 8 STRAIGHTENER SUPPORT	WELD AT COLUMN BASE	TORSION + BENDING	FATIGUE: $K_f f_t > F_{TY} \gg F_E$

GRUMMAN

V82-0630-040P

STRENGTH SUMMARY OF EXISTING CBCF (CONTD)

PARTS WITH ADEQUATE STRENGTH

Many of the parts seem to have an adequate margin of safety under ±50g loads. These components are indicated on the facing page.

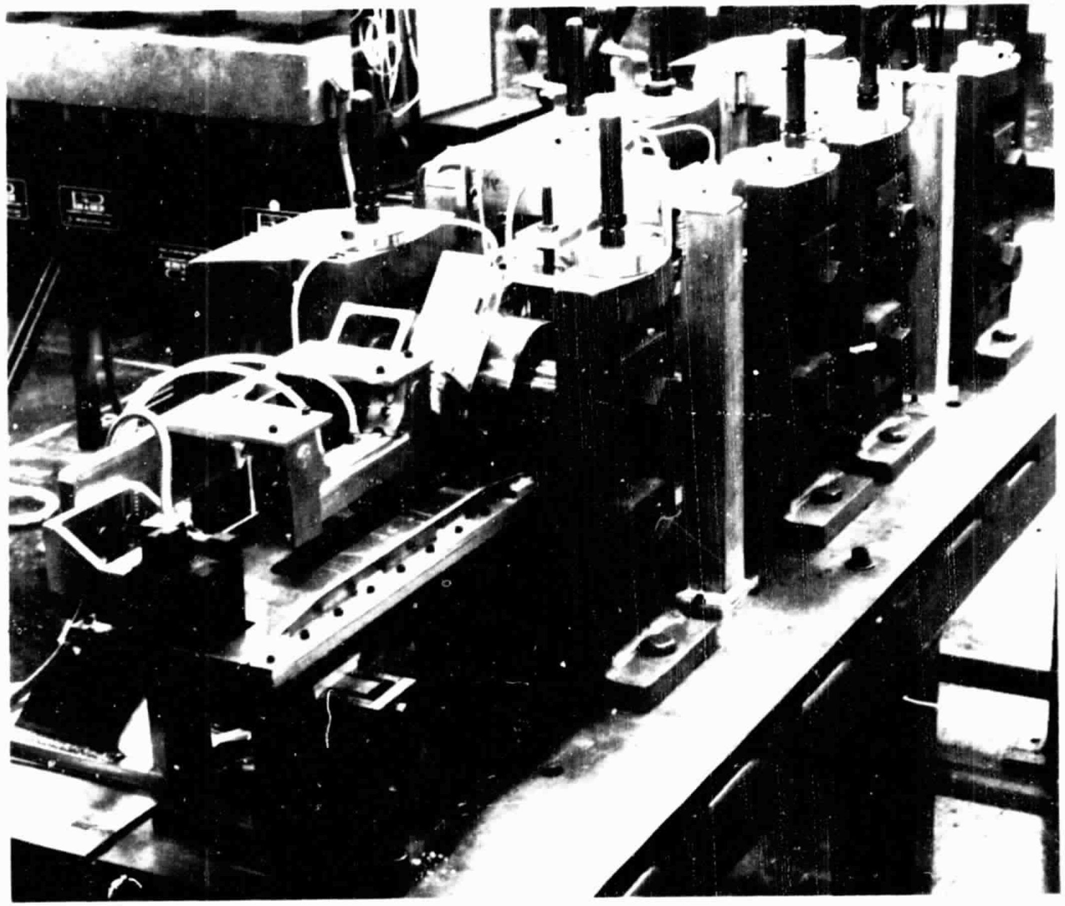
However, two cautions are offered before agreeing that the parts on this list have adequate strength. In some instances, accurate data on material, material strength or part dimension was lacking. Engineering estimates were used to make some assessment in the absence of verified data. This occurred in the analyses of the cast iron components and the quartz heating lamps. The second caution pertains to knowledge of applied loads. Until the dynamic characteristics of the entire experiment are known, adequacy of part strength remains unknown.

The importance of component testing is highlighted by NASA experience with the quartz heating lamps. An acoustic vibration test simulating Shuttle launch was applied to a small group of the quartz heating lamps. Fifty percent of the lamp filaments failed in this environment.

STRENGTH SUMMARY OF EXISTING CBCF (CONTD)

PARTS WITH ADEQUATE STRENGTH

- PYROMETER SUPPORT
- STATION 1 HEATER/PYROMETER SUPPORT
- ALL ATTACHMENT HARDWARE
- QUARTZ HEATING LAMP
- YODER ROLLING MILL
  - BEARINGS (ALL)
  - SHAFTS FOR ROLLER DIES
  - OUTBOARD CASTING
    - 50% MS FOR FATIGUE (F_E)
  - INBOARD CASTING



RECOMMENDATION: ALL VENDOR COMPONENTS SHOULD BE VIBRATION TESTED EARLY IN PROGRAM TO VERIFY STRENGTH/DYNAMIC RESPONSE

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

GRUMMAN

V82-0630-033P

CBCF FLIGHT EXPERIMENT GOALS

The three goals highlighted on the facing page amplify the main goal of developing a necessary technology with low costs.

The phrase "suitcase flight experiment" implies that total experiment costs be less than \$10M and that the experiment should be available for flights of opportunity that may develop. This implies that the experiment have a minimum impact on other payloads which share the Orbiter's payload bay. Also, that the CBCF Flight Experiment be compatible with many different payload bay locations.

Since Orbiter payload bay space is expensive (either cash out of pocket for a commercial user or lost revenue to NASA for their own payloads), it is more efficient to evaluate all aspects of composite beam builder technology on a single flight rather than using 2 or 3 different flights. This is particularly valid if the added subsystems (over and above the minimum required to demonstrate composite beam cap fabrication), like fastening and magazine subsystems, do not add to launch costs.

The only technologies which must be evaluated on a CBCF Flight Experiment are those activities which can not be evaluated adequately in ground laboratories. In general, these are phenomena which may be influenced by the absence of gravity, since adequate size thermal and airless environments are available on earth.

CBCF FLIGHT EXPERIMENT GOALS

- LOW COST, SUITCASE FLIGHT EXPERIMENT
- VERIFY MAJOR COMPOSITE BEAM BUILDER TECHNOLOGY ISSUES IN A SINGLE FLIGHT
  - LAUNCH COSTS EXCEED EXPERIMENT COST BY 2:1 AFTER 1985
- TECHNOLOGY ISSUES REQUIRE FLIGHT IFF UNIQUE CHARACTER OF FLIGHT ENVIRONMENT (ZERO G) IS
  - TOO EXPENSIVE TO REPRODUCE ON EARTH; OR
  - IMPOSSIBLE TO REPRODUCE FOR TIME REQUIRED TO STUDY PHENOMENA UNDER INVESTIGATION

GRUMMAN

V82-0630-047P

TECHNOLOGICAL JUSTIFICATIONS OF FLIGHT EXPERIMENT

The next several pages list technical phenomena which may occur while utilizing composite beam fabricating technology in space. The occurance of some of the phenomena may be evaluated by inexpensive ground tests. If these tests establish the existence of a phenomenon of concern, it seems likely that evaluation at near zero gravity for tens of minutes (much longer than is available for airborne zero g) will be required to understand all the implications of the event.

The facing page deals with the generation and movement of contaminants during composite beam fabrication. While it is clear that solid particles will migrate very differently in space (as compared with a 1g laboratory), the case for gases is cloudy. The quantity and kind of gas molecules emitted during these fabrication processes is currently unknown. If the quantity/machine-geometry relationship is such that a gas cloud is not formed, then no significant difference is anticipated between behavior in ground thermal vacuum chambers and in space. However, should a gas cloud form, the absence of convective flow should produce significant differences.

The machinery outlined in this report is substantially different from all space based machines to date. The cutting motions, rapid accelerations and decelerations, impact forces, abrasions, etc. are more typical of machines that will use space as a working place to do a job. These motions are contrasted with the instrument types of motion found on current space machinery (e.g., solar array drives, hermetically sealed gyros, etc.). Working machines of all types will generate solid particles. Uncontrolled migration of these particles are a hazzard to the machines that generate them as well as to nearby neighbors. Consequently, a solid particle containment system is required as part of composite beam builder technology. It is also needed for other types of working machines (as opposed to instrument machines) that will be used in space.

CONTAMINATION CONTROL IN ZERO G

- PARTICLE MIGRATION IS VERY DIFFERENT IN ZERO G VS 1 G

	SOLIDS	GASES
SOURCES OF CONTAMINANTS	• CAP CUTOFF • ABRASION OF CAP/ROLLERS • LUBRICANT WEAR • BRACE TRANSPORT • IMPACTS OF BRACE CLAMPING TOOL, INDUCTION FASTENING TOOL & GEAR TEETH • ABRASION OF CAP & GUIDES • ABRASION OF SEALS ON SHAFTS	• LOCAL VERY HIGH SURFACE TEMPS MAY BE REQD TO HEAT CAP INTERIOR ADEQUATELY; VAPORIZING OR OFFGASSING MAY RESULT • LOW VAPOR PRESSURE OF MOLTEN THERMOPLASTIC MAY RELEASE GAS MOLECULES • LUBRICANT VAPORIZATION DURING MACHINE OPERATION
POTENTIAL PROBLEMS	• MIGRATION OF GR, AL OR STEEL PARTICLES MAY PRODUCE SHORT CIRCUIT • MIGRATION OF TFP &/OR PES PARTICLES MAY PRODUCE HIGH ELECTRICAL RESISTANCE AT SWITCHES	• OPAQUE PARTICLES MAY OBSCURE OPTICAL SURFACES (QUARTZ LAMP COVERS, REFLECTOR, PHOTO CELLS) • GAS CLOUD NEAR CAP MAY DIFFUSE RADIANT HEAT ENERGY
CONTROL METHODS REQUIRING VERIFICATION	• ELECTROSTATIC CAPTURE SYSTEM • ADHESIVE RETENTION SYSTEM	

GRUMMAN

V82-0630-050P

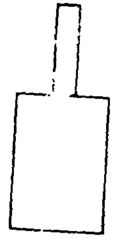
CAP STRUCTURAL QUALITY

Two different phenomena are outlined on the facing page. The first, triaxiality or biaxial effects, occurs in 1g testing of a CBCF. As a cap is produced, the cap sticking out of the end of the CBCF develops a normal stress (σ_A) on the cap within the CBCF that is still being formed into its final shape. The normal stress is developed by the weight of the cap (for vertical CBCF) or the bending moment generated by cap weight (for horizontal CBCF). Since the presence of normal stress σ_A on an element will influence the magnitude of the forming stress (σ_F) which produces the curved sections of the cap, two caps, roll formed with the same roller die settings on earth and in space, will spring back to different angular positions. An estimate of the magnitude of this effect can be obtained on the ground by producing a cap with a horizontal CBCF and then producing a second cap of equal length with the CBCF rotated 180° about a horizontal axis.

The second phenomena appears to be the more serious one. Since a 1g bias force is absent in space, a chattering, vibratory type of power transmission is known to take place as shafts, bearings and gears meander through the clearances that must exist between parts with relative motion. This may cause the cap material to wander off centerline, producing an unsymmetrical cap. Should this occur, solutions are available to correct the problem. However, since it is not currently known if the problem exists, no solutions have been built into the machinery.

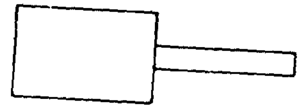
CAP STRUCTURAL QUALITY

IN 1 G FIELD

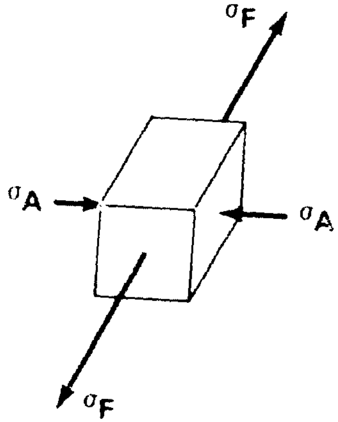


VERT!CAL
CBCF

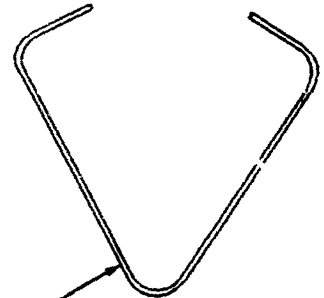
OR



HORIZONTAL
CBCF

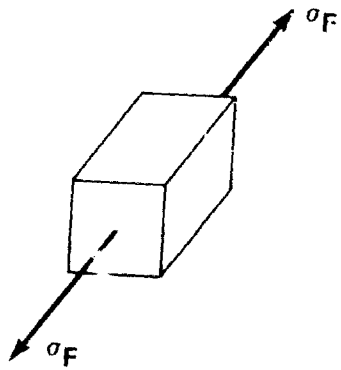


⇒ BIAXIAL EFFECTS



- AXIAL COMPRESSIVE STRESS σ_A

IN ZERO G



⇒

- SPRINGBACK ANGLE WILL CHANGE

- CLEARANCE SPACES BETWEEN SHAFTS & BRGS, GEAR TEETH PERMIT CHATTERING, BOUNCING TYPE OF POWER TRANSMISSION
- CLEARANCE BETWEEN CAP & DIE ROLLER WITHOUT 1 G BIAS FORCE, POSSIBLY PERMITS CAP TO MOVE TO NEW POSITIONS DURING FORMING

V82-0630-051P

GRUMMAN

THERMOPLASTIC WELDING

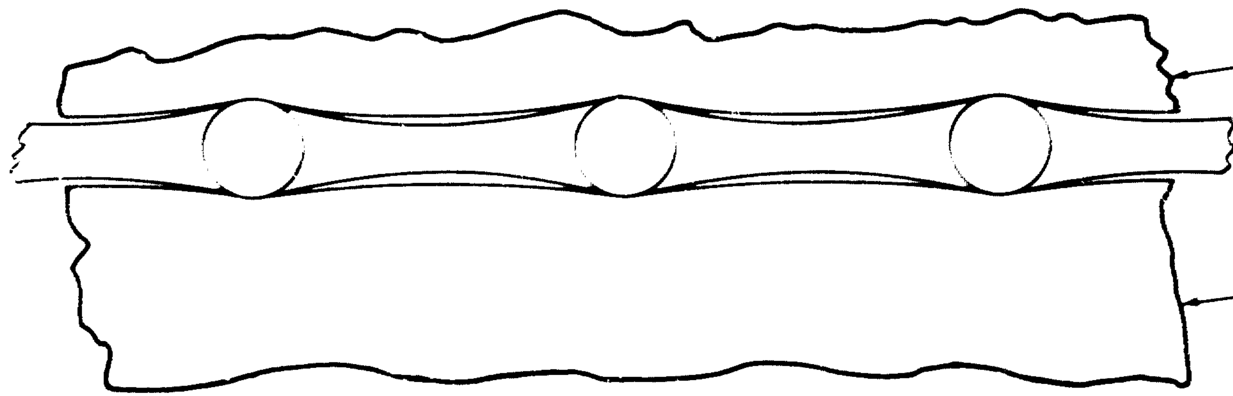
On earth, gravity forces exceed surface tension forces. The result is that liquids tend to wet the surfaces that contain them, since there aren't enough forces available to pull the liquid away from surrounding surfaces. However, this is not the case in space.

The diagram on the facing page attempts to describe the phenomena. The solidified thermoplastic is shown having two concave sides – a minimum free energy surface formed by surface tension while the material was molten – with the largest amount of material next to the wire mesh (since the wire mesh is the heat source, most molten material is generated here). The surfaces of both cap and brace are also shown as solidified free energy surfaces, but with convex curvature since most material is lost near the wires.

The main point of the diagram is the discontinuous attachment of cap to solidified thermoplastic and of solidified thermoplastic to brace. With contact only in the region of the wires, the shear strength of this joint may be reduced.

The discontinuities are possible only if molten thermoplastic is able to flow through and outside of the edges of the mesh, leaving less material in the interior of the fastened region than was there originally. Samples of Induction Fastening performed on earth show that thermoplastic does flow through the mesh and outside the joint.

THERMOPLASTIC WELDING



- POSSIBLE ZERO G CONFIGURATION OF INDUCTION FASTENING JOINT
- LOWEST FREE ENERGY SURFACE CONFIGURATION
  - ABSENCE OF HYDROSTATIC HEAD
  - SURFACE TENSION DOMINATES MOLTEN SHAPE
  - MAY PRODUCE DISCONTINUOUS ATTACHMENT OF MOLTEN & SOLID PLASTIC WHICH MAY REDUCE STRENGTH OF JOINT
- ZERO G FORMED JOINT STRENGTHS MAY VARY SIGNIFICANTLY BETWEEN INDUCTION FASTENING (WITH AN IMBEDDED WIRE MESH) & ULTRASONIC WELDING
  - THESE PROCESS EFFECTS SHOULD BE GENERIC TO ALL TYPES OF THERMOPLASTICS

EMI & INTEGRATION

Component testing will be used to determine acceptability of individual elements. However, maximum confidence in proper system behavior is only achieved after the entire system is operated successfully in its normal working environment. The flight experiment outlined in this document will provide that level of confidence for composite beam builder technology.

EMI & INTEGRATION

- TEST SYSTEM'S SENSITIVITY TO ORBITER'S ELECTROMAGNETIC INTERFERENCE & BACKGROUND RADIATION
  - PHOTOELECTRIC SENSORS
  - PYROMETERS
  - Z80 MICROCOMPUTER CHIP
- EVALUATE & VERIFY INTEGRATED SYSTEM
  - ALL COMPONENTS FUNCTIONING TOGETHER IN A LOW G, HIGH VACUUM POOR HEAT TRANSFER ENVIRONMENT
  - LUBRICATION UNDER ACTUAL LOADING CONDITIONS
  - SIMULTANEOUS VERIFICATION OF ALL COMPONENTS OF COMPOSITE BEAM BUILDER TECHNOLOGY

GRUMMAN

FLIGHT EXPERIMENT TECH JUSTIFICATIONS – SUMMARY

Some of the issues summarized on the following pages are unique to composite beam builder technology. Others, however, are generic to many types of machinery that will ultimately see use in space. For example, the generation of solid particles with motions that have relative sliding, impacts against stops, shearing of minute particles, etc. These generated particles are potential hazzards to electrical systems. Dielectric plastic particles, if they accumulate on contactor surfaces, can raise contact resistance to destructively high levels. Conducting particles of metal or graphite could short circuit switches and machinery. Consequently, the migration of these particles must be controlled. Development of a solid particle contamination control system for the CBCF Flight Experiment will benefit future users of machinery in space.

A similar argument can be offered for the development of a technology for fastening thermoplastic composite components, both for space fabrication and repair of composite structures.

FLIGHT EXPERIMENT TECH JUSTIFICATIONS – SUMMARY

COMPOSITE BEAM BUILDER PROCESS	RESULTING PROCESS/ PRODUCT BEHAVIOR	IMPLICATIONS OF SPACE ENVIRONMENT	TEST UNCERTAINTIES
1) CUTOFF, ROLL FORM, MECH POWER TRANS	SHEARING/SLIDING/ IMPACTS: GENERATE PARTICLES OF GR, GR/PES, PES, TEFLON, AL & STEEL	PARTICLES TRAVEL WITH RANDOM VEL & DIREC-TION; POTENTIAL HAZARD TO ELECTRICAL SYST	MEASUREMENT OF NUMBER & SIZE OF PARTICLES
2) CAP HEATING FOR ROLL FORMING	POSSIBLE: GASES EMITTED AT CAP	GASES STAY NEAR CAP SURFACE	CLOUD IMPEDES HEATING PROCESS
3) ELECTROSTATIC CAP-TURE OF DEBRIS		DIFFERENT PARTICLE TRAJECTORIES IN ZERO G	
4) ADHESIVE RETENTION OF DEBRIS		DIFFERENT IMPACT MOMEN-TUM IN ZERO G	
5) ROLL FORMING	TRIAXIALITY: 3D STRESS DISTRIBUTION FROM CAP WEIGHT	ELIMINATES STRESS IN AXIAL DIRECTION	CHANGE IN SPRING-BACK ANGLES FROM GROUND RESULTS
6) ROLL FORMING	CLEARANCES EXIST BE-TWEEN MACHINE ELEMENTS & BETWEEN CAP & MACHINE	RANDOM LOCATIONS; CHATTERING, BOUNCING, ETC OF MACHINE ELEMENTS	UNKNOWN EFFECT ON CAP QUALITY (BENDING, TWISTING, UN-EQUAL FLANGES, ETC)

GRUMMAN

V82-0630-048P

FLIGHT EXPERIMENT TECH JUSTIFICATIONS – SUMMARY (CONTD)

COMPOSITE BEAM BUILDER PROCESS	RESULTING PROCESS/ PRODUCT BEHAVIOR	IMPLICATIONS OF SPACE ENVIRONMENT	TEST UNCERTAINTIES
7) THERMOPLASTIC FASTENING	MELTING OF THERMOPLASTIC	SURFACE TENSION FORCES DOMINATE LIQUID SHAPE	POSSIBLE WEAKEN-ED BOND
8) SENSING & CONTROL	COMMAND INITIATION, COUNTING, SPEED REGULATION	NATURAL RADIATION & ORBITER EMI MAY GIVE FALSE SIGNALS	UNKNOWN SYSTEM RESPONSE

GRUMMAN

V82-0630-049P

STRUCTURAL CONFIGURATION OF SPACE FABRICATED ARTICLE

The facing page outlines the logic used to determine what the output of a CBCF Flight Experiment shall be.

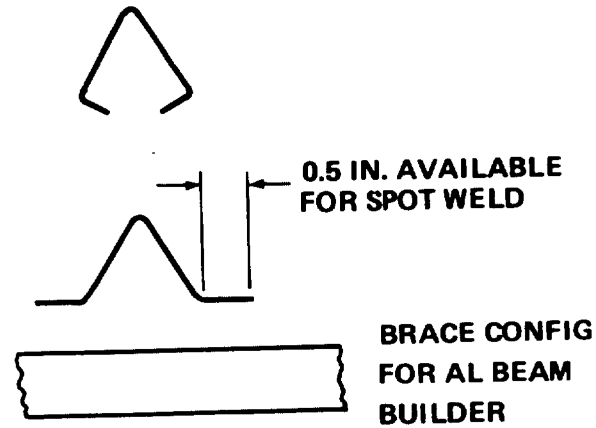
The shape of the member produced by the rolling mill is fixed at the current capability of the CBCF. This shape is shown in detail on page 5. Since launch costs are primarily determined by the length of the payload bay occupied by a payload, it was decided that the fabricated caps should not add any additional length to the volume of payload bay occupied by the CBCF Flight Experiment. All fabricated caps must be returned to earth, both for examination of cap quality and to prevent additional space junk at LEO. Consequently, cap storage orientation for earth return is across the payload bay. This limits the maximum length of fabricated cap to 15 feet.

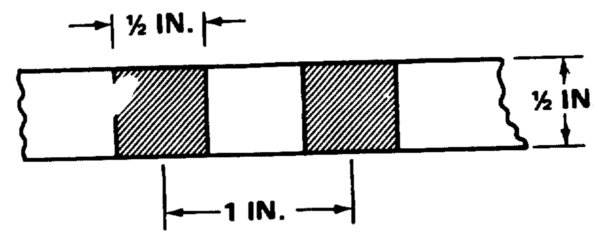
The fastening geometry was selected to be representative of Composite Beam Builder (CBB) fastening. Since this system has not been designed, the Aluminum Beam Builder geometry was used as a model. This implied a 1/2 inch wide fastened region and a 1/2 inch wide simulated brace. The 1/2 inch spot length was selected for aesthetic reasons. A single spot brace to attach the cap is unsuitable, both for this flight experiment and production beam builders because it doesn't leave any margin for error. Two fastened spots were selected to provide redundancy at minimum cost. A 1 inch pitch between spots typifies CBB needs and provides a reasonable moment capability for the flat strip "brace".

Production of a typical 1 meter deep beam on a CBB will require cap production to stop at 5 foot intervals to permit attachment of braces. Thus, the flight experiment will also stop cap production at 5 foot intervals for brace attachment. With an upper limit for cap length of 15 feet, this implies that three braces will be attached to each cap. A cap length of 14 feet was selected to allow 5 fabricated caps to be stored in the payload bay below the main experiment machinery.

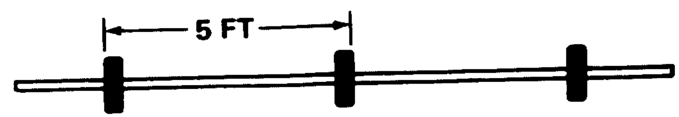
STRUCTURAL CONFIGURATION OF SPACE FABRICATED ARTICLE

- USE CAP SHAPE PRODUCED BY ROLL FORMING MILL
  - MAX LENGTH TO FIT INSIDE PAYLOAD DIA 13 FT $< L_{MAX} <$ 15 FT
- FASTEN SOMETHING (A "BRACE") TO CAP THAT REPRESENTS COMPOSITE BEAM BUILDER TECHNOLOGY
  - USE AL BEAM BUILDER AS MODEL
  - MAX BRACE WIDTH AVAILABLE FOR FASTENING = ½ IN.
- MINIMUM COST "BRACE" FOR FLIGHT EXPERIMENT
  - FLAT STRIP ½ IN. WIDE
  - LENGTH DETERMINED BY DISPENSING & FASTENING SYSTEM DESIGNS (14 IN.)
- NUMBER OF FASTENING SPOTS > 1 TO INSURE BRACE REMAINS ATTACHED AFTER SINGLE FAILURE
  - CHOOSE 2 SPOTS FOR MIN COST
- SELECTED SPOT SIZE: ½ X ½ IN.
- NUMBER OF BRACES PER CAP
  - SEPARATE BY 5 FT INTERVALS TO SIMULATE BEAM BUILDER ⟹ 3 BRACES PER CAP





FASTENING CONFIGURATION



STRUCTURAL CONFIG

GRUMMAN

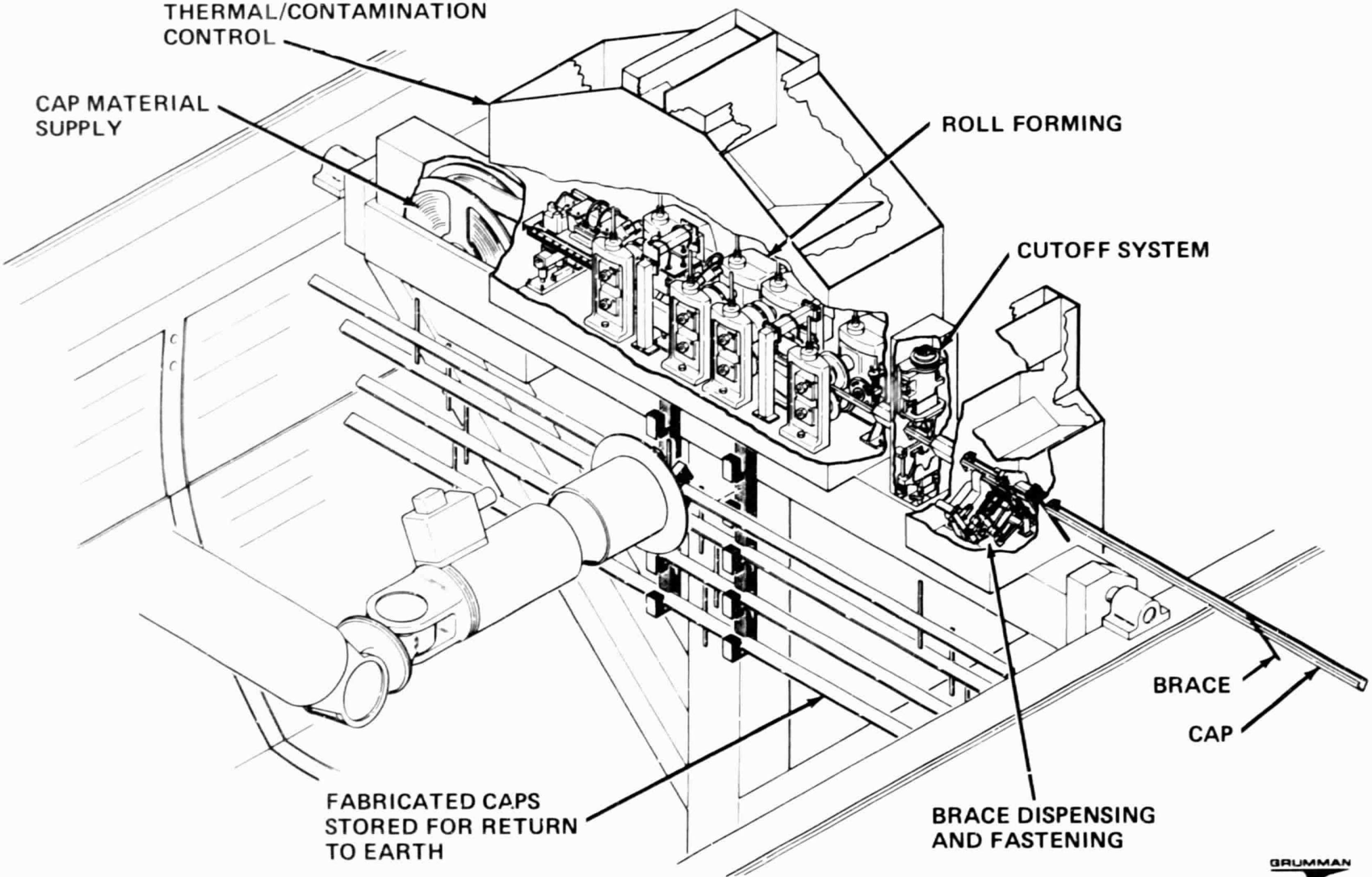
V82-0630-018P

MAJOR ELEMENTS OF CBCF FLIGHT EXPERIMENT

The major elements of a flight experiment are shown to scale within the Orbiter's payload bay on the facing page. The foreground contains part of the RMS arm as it moves a fabricated cap toward its storage facility.

The next section of this report defines some of the details of the recommended flight experiment and the machinery to be used.

MAJOR ELEMENTS OF CBCF FLIGHT EXPERIMENT



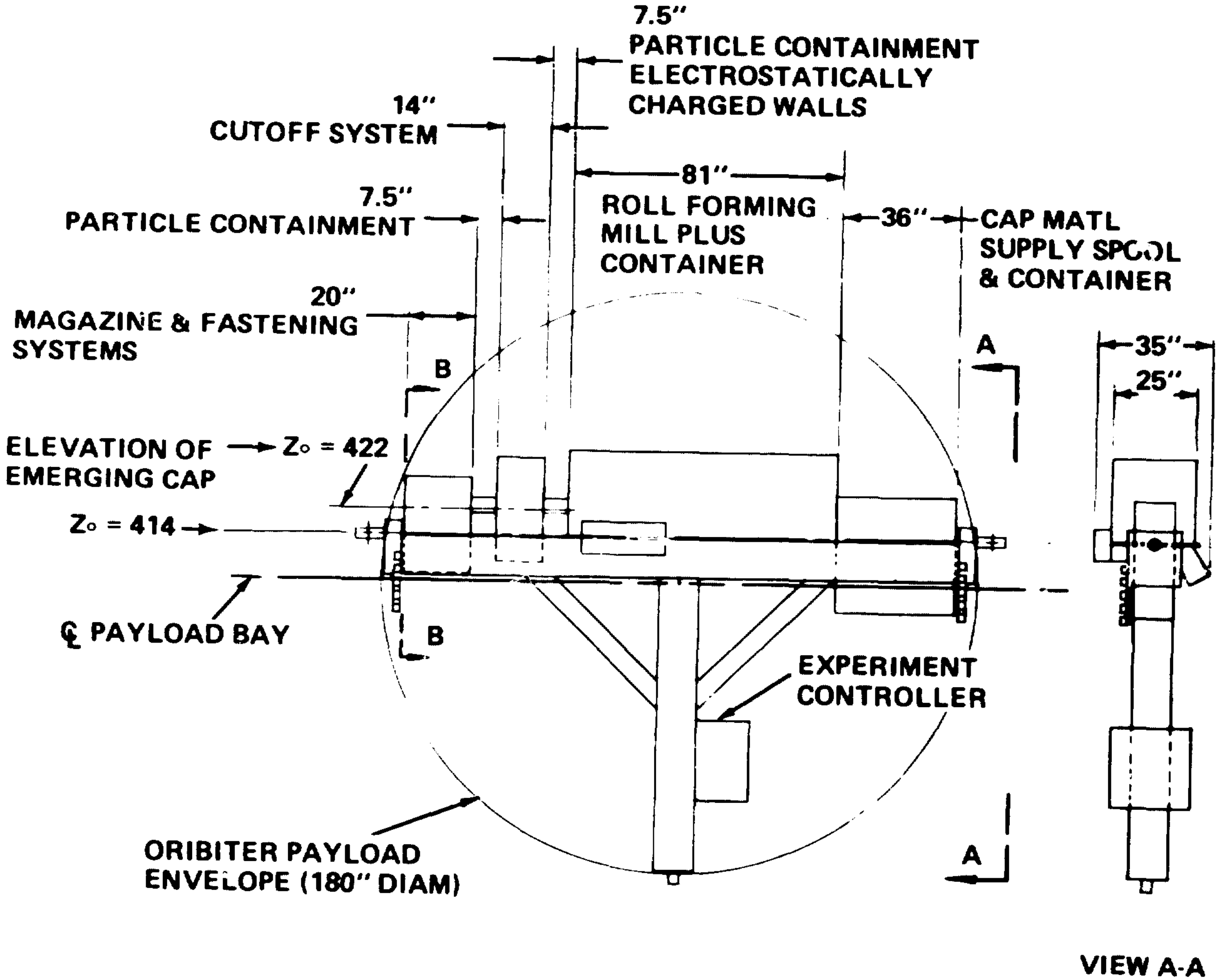
1230-033B

CBCF FLIGHT EXPERIMENT "STRAWMAN"

At a very early point in this study, the "Strawman" design was generated to permit an early overall assessment of the flight experiment. It was intended as a focal point for criticism and suggestion.

One of the conclusions drawn from this effort was that experiment length was more of a launch cost driver than experiment weight (outlined on the following page). Under existing launch pricing procedures, 1 foot of payload bay length costs a payload user as much as the charge for 1000 pounds of payload weight.

CBCF FLIGHT EXPERIMENT "STRAWMAN"



CROSS SECTION THROUGH ORBITER
PAYLOAD BAY

ORIGINAL PAGE IS
OF POOR QUALITY

V82-063C-001P

ROM WEIGHT ESTIMATE FOR "STRAWMAN"

This early weight estimate of "Strawman" was composed of accurate data on existing hardware (e.g., the rolling mill stations, gearboxes and baseplate), crude estimates on undefined and undesigned systems (e.g., the fastening system) and a number of estimates whose quality lie between the two previous extremes.

ROM WEIGHT ESTIMATE FOR "STRAWMAN"

	WEIGHT (LB)
ROLLING MILL	
4 STATIONS + MOTOR & GEARBOXES, STEEL BASEPLATE	1310
QUARTZ LAMPS & SUPPORTS (8)	40
OPTICAL PYROMETERS & SUPPORTS (8)	40
PRESENCE SENSORS (PHOTOELECTRIC) (4)	10
3-FT DIAMETER STORAGE SPOOL (1)	40
CONTAMINATION CONTAINMENT	
ROLLING MILL	70
STORAGE REEL	30
CUTOFF SYSTEM	30
COLD WALLS & COOLING SYSTEM	20
CUTOFF SYSTEM	200
MAGAZINE & STRIPS (20) & DISPENSING SYSTEM	10
FASTENING SYSTEM (INCLUDING SUPPORT STRUCTURE)	140
EARTH RETURN SUPPORTS (10)	20
RMS ADAPTER (OPTIONAL FOR NO EVA)	10
CONTROL SYSTEM	40
SUBTOTAL	2010 LB
PAYLOAD BAY SUPPORT STRUCTURE (19% MASS FRACTION FOR LOW COST STRUCTURE)	390
TOTAL WEIGHT	2400 LB

GRUMMAN

1230-037B

LIGHTWEIGHT CBCF

The rolling mill components supplied by the Yoder Company were designed to form steel parts, which are much thicker than the .040 inch caps, at much higher speeds than are contemplated for space fabrication. Since they were designed for much higher loads than space fabrication applies, they are far heavier than we need. At a total weight of 1250 pounds, the components in the list on the opposite page represent a significant percentage of the total weight of the flight experiment.

LIGHTWEIGHT CBCF

- YODER ROLL FORMING EQUIPMENT IS VERY HEAVY
  - DESIGNED FOR MUCH HIGHER LOAD APPLICATIONS
- CANDIDATE WEIGHT REDUCTION COMPONENTS
  - ROLLER DIES
  - ROLLER DIE SHAFTS
  - GEAR TRAINS
  - HOUSINGS (STANDS)
  - BASE SLAB
- EVALUATE 2 LIGHTWEIGHT CBCF CONFIGURATIONS:

A ⟶ LOW RISK, MACHINE EXISTING PARTS, SIMPLE MATERIAL REPLACEMENT

B ⟶ ALL OF A + HIGHER RISK REPLACEMENT OF CASTINGS

- COST OF ABOVE CHANGES ~ < $100,000

1230-018B

CBCF WEIGHT REDUCTION OPTIONS

CONFIGURATION A

An evaluation of some existing Yoder supplied components was made with enough depth of cut to ensure that significant weight savings are available.

The roller dies apply tractive forces and deforming forces to change the shape of the cap material. Both sides of a roller mount on a 1½ inch dia shaft with a keyway. To remove material from the center of a roller, one side of a roller is opened up in diameter to accommodate a bottle boring tool whose diameter is greater than 1½ inches. This procedure is substantially less expensive than confining both ends of the tool to the smaller diameter. To complete a roller, the large diameter opening is closed by bolting or riveting a plate to the roller. Roller wall thickness was arbitrarily selected in the range of $30 < D/t < 40$. Since the magnitude of force acting on a roller during forming operations is unknown, no strength or stiffness evaluations were made for the light-weight roller design. Weight assessments of present and possible rollers are found on the facing page. Analysis of the weights of roller dies for the Aluminum Beam Builder (which form a similarly shaped cap) indicates an average roller weight of 41 pounds. This value is assumed valid for the CBCF. It can be reduced to 10 pounds by removing 31 pounds with the above bottle boring procedure.

The rollers are supported by a 1.5 inch diameter shaft which is slotted lengthwise to accept a key. Since the shaft length exceeds 20 inches, a rifle drilled .75 inch dia hole on the centerline of the shaft will remove over 2.5 lbs from each shaft. This hole size leaves enough wall thickness for a longitudinal slot and a stepped down thread. Since operating loads are unavailable, strength and stiffness analyses were not conducted.

The shafts are supported on inboard (powered) and outboard (unpowered) ends by cast iron stands. The inboard stand weighs about 80 lbs and contains a substantial amount of power transmission components (4 spur gears, 1 worm/gear set, bearings, adjusting screws, etc.) These power transmission components are compact, but wide enough to sustain high forming forces. Since forming forces are very low during fabrication of composite thermoplastic caps, gear widths can be significantly reduced.

CBCF WEIGHT REDUCTION OPTIONS

CONFIGURATION A				
COMPONENT	ORIGINAL WEIGHT (LB)	DESCRIPTION OF CHANGE	REDUCED WEIGHT (LB)	WEIGHT SAVED (LB)
1. ROLLER DIES	41#/DIE	BOTTLE BORE EXISTING STEEL DIES	10#/DIE	250
2. GEAR TRAIN TO UPPER DIE	12#/STATION	REDUCE FACE WIDTH TO 1/2"	5#/STATION	28
3. ROLLER DIE SHAFT	10#/SHAFT	RIFLE DRILL 3/4" DIA HOLE	7.5#/SHAFT	20
4. BASE SLAB (STEEL, 7/8" THICK)	512#	REPLACE WITH 1/4" THICK ALUMINUM PLATE	52#	460
TOTAL SAVED FOR CONFIGURATION A = 760 LB				

GRUMMAN

1230-0198

CBCF WEIGHT REDUCTION OPTIONS

CONFIGURATION B

The inboard housing is a thick walled casting (about .3 in thick) with many support points and load paths for bearings. The outboard stand is a thick walled casting (about 1.1 in and 1.5 in thick). Both housings are made of cast iron. A change to cast or welded aluminum is possible because the lower strength aluminum will be subjected to lower loads from the light weight rollers.

The roll forming machines are fastened to a 7/8" thick steel plate. Since the flight experiment machine is continuously supported on the transverse beam, the plate can be changed to aluminum in a much thinner gauge.

CBCF WEIGHT REDUCTION OPTIONS (CONT)

CONFIGURATION B				
COMPONENT	ORIGINAL WEIGHT (LB)	DESCRIPTION OF CHANGE	REDUCED WEIGHT (LB)	WEIGHT SAVED (LB)
1. ROLLER DIES	41#/DIE	BOTTLE BORE AL ROLLERS	3.5#/DIE	300
2. GEAR TRAIN TO UPPER DIE	12#/STA	REDUCE FACE WIDTH TO 1/2"	5#/STATION	28
3. POWERED ROLLING STATION HOUSING	43#/STA	REPLACE CAST IRON WITH AL CASTING OR WELDMENT	16#/STATION	108
4. UNPOWERED ROLLING STATION HOUSING	25#/STA	REPLACE C.I. WITH AL CASTING OR WELDMENT	9#/STA	64
5. ROLLER DIE SHAFT	10#/SHAFT	RIFLE DRILL 3/4" DIA HOLE	7.5#/SHAFT	20
6. BASE SLAB	512#	REPLACE WITH 1/4" ALUMINUM PLATE	52#	460
TOTAL SAVED FOR CONFIGURATION B = 980 LB				

GRUMMAN

1230-020B

LIGHTWEIGHT CBCF SELECTION

CHOOSE CONFIGURATION B { MACHINE WEIGHT = 350 LB; WEIGHT SAVED = 980 LB }

JUSTIFICATION:

- SPACE FABRICATION WILL BENEFIT IF SIGNIFICANTLY LIGHTER WEIGHT MACHINES ARE ASSOCIATED WITH THE PROGRAM, AND,
- THE COST OF IMPLEMENTING THESE CHANGES (< $100,000) IS LOST IN THE NOISE OF TOTAL PROGRAM COSTS.
- DEVELOPMENT RISKS ARE SMALL.

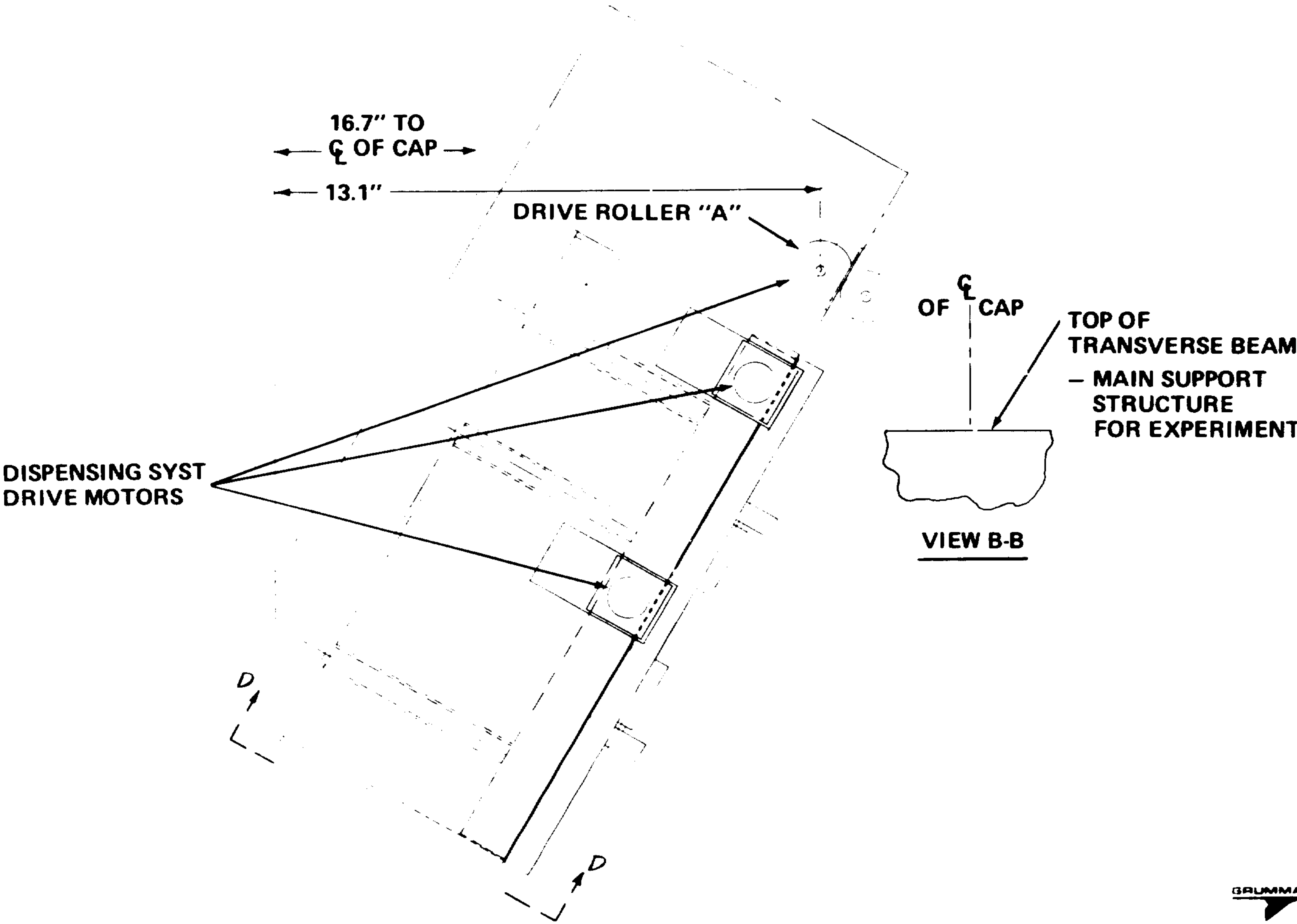
MAGAZINE & DISPENSING SYSTEMS

The decision reached earlier to fly all major elements of composite beam builder technology requires that a system which stores a supply of braces be developed for the flight experiment. Further, that this system must be capable of dispensing and delivering to some transport system a single brace on command at least 15 times (for fabrication of 5 caps).

The drawing is a view looking parallel to the longitudinal axis of the cap. A section of a brace is shown between two rollers which are part of the dispensing systems. Twenty braces (graphite/polyethersulfone strips .040 inch by .5 inch by 14 inch) are stored in a region just to the left (in the drawing on the facing page) of the dispenser (labeled transfer shelf in figure). They are forced against the transfer shelf by 3 springs whose low spring rate approximates constant force devices. Two drive motors attached to the magazine translate a brace upward to the right by friction forces developed between drive rollers and brace.

View D-D, on the following diagram, shows some of the details of the dispensing system.

MAGAZINE & DISPENSING SYSTEMS

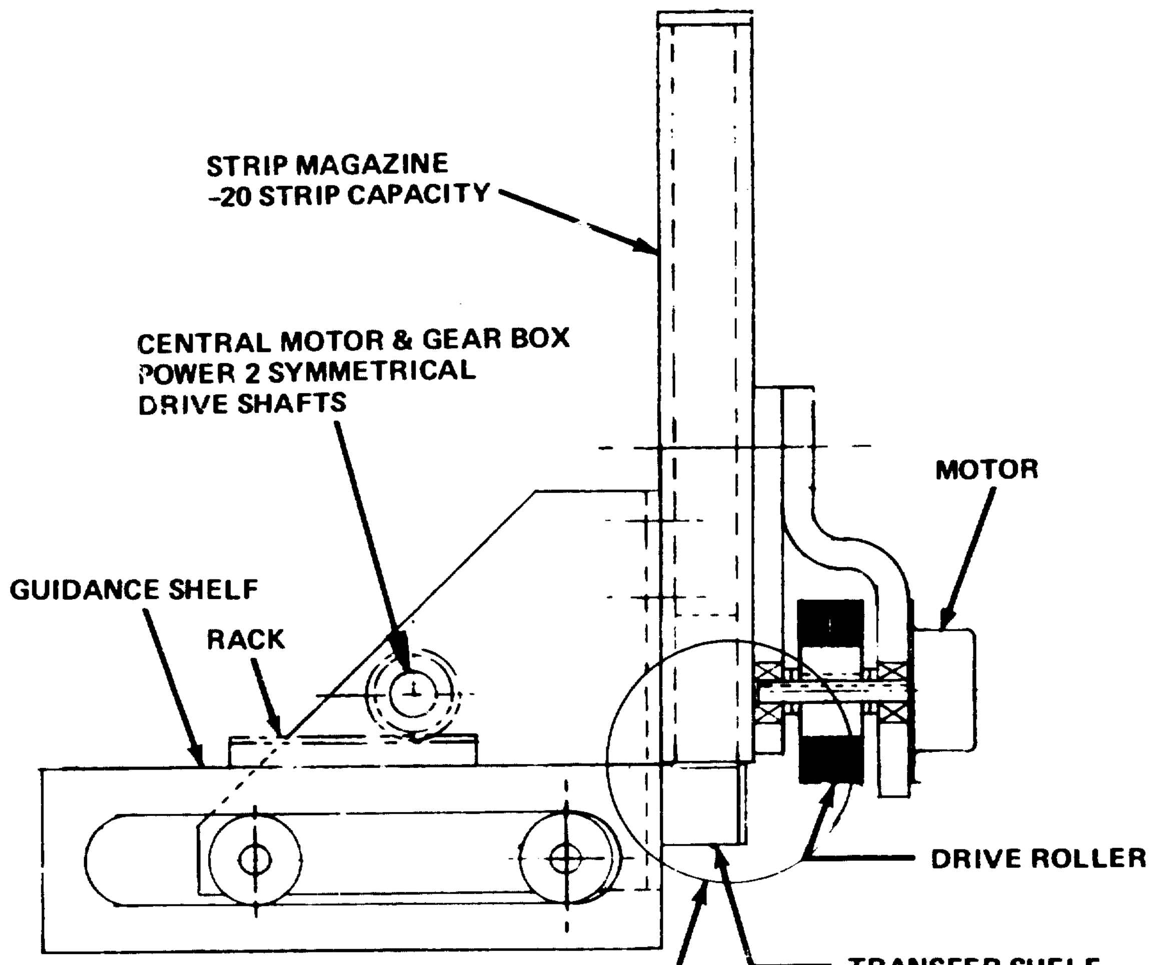


V82-0630-011P

BRACE DISPENSING SYSTEM

The dispensing system delivers a brace from the magazine to the fastening region by imparting 2 successive translational motions to it. The first motion is translation to the right (on the facing page) as the pinions attached to the central motor drive shafts produce horizontal forces on the racks which are fastened to 2 guidance shelves. These guidance shelves, both of which are fastened to the transfer shelf, are supported by pairs of rollers which engage central slots in the shelves. A brace is held against the upper surface of the transfer shelf by forces from the magazine springs, or, by forces from the deflected fibers on the fiber drive rollers. This can be seen on the following diagram, a blow up of Detail F.

BRACE DISPENSING SYSTEM



VIEW D-D
(TYPICAL 2 PLACES)

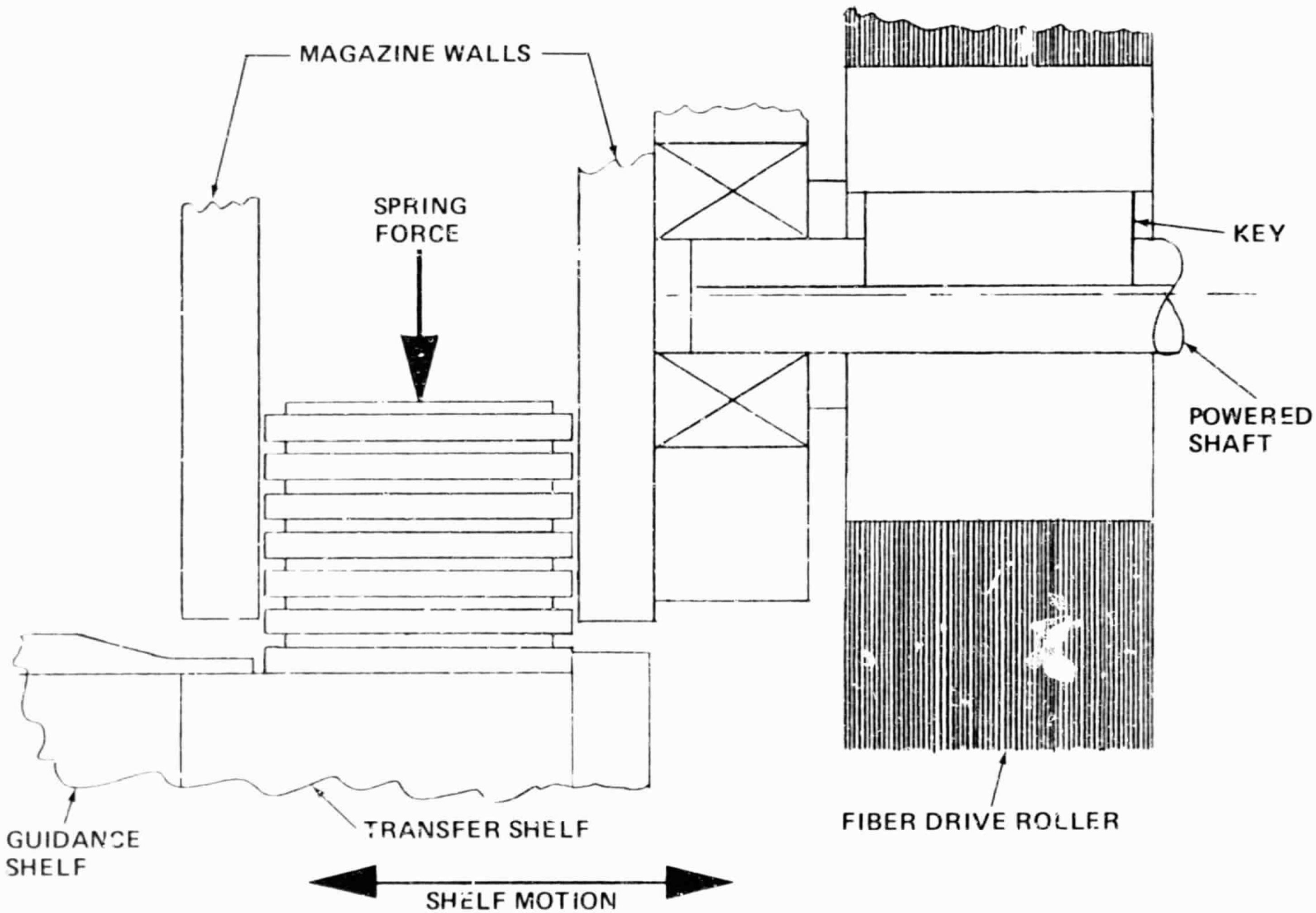
1230-035B

DETAIL F – BRACE DISPENSING AND TRANSFER

Each brace is made up of two major elements. The main brace structure is attached to two thin wire grids which become hot when an oscillating current flow is induced in them by an induction fastening tool. A wire grid is shown schematically by a narrow, horizontal rectangle under the "spring force" arrow in the diagram. The brace structure (.040" thick) is shown to scale as a larger rectangle directly beneath the wire grid. Seven braces are shown in the drawing.

As the guidance-shelf/transfer-shelf unit moves to the right, the entire brace stack moves with it until they hit the right wall of the magazine. The shelves and lowest brace continue to move to the right. The lowest brace is "picked" from the stack by the lip attached to the shelves on the left side of the stack. This lip quickly thickens so it supports the left side of the stack as the shelves move to the right. As the lowest brace slides under the brace stack, pressure from the stack keeps it against the transfer shelf. After moving a distance to the right, first the transfer shelf, and then the brace, deform the fiber drive roller. The distance between the fiber drive roller and magazine wall should be small enough to permit the fibers to exert a controlling downward pressure on the brace before the brace leaves the constraining forces of the brace stack. After brace stack constraints are left, friction forces from the rotating fiber roller translate the brace along the top of the transfer shelf into the drive-roller/traction-roller pairs shown on pages 51 & 59. These feed the brace into the fastening system. They also provide holding forces until the fastening system takes over.

DETAIL F – BRACE DISPENSING & TRANSFER



GRUMMAN

V82-0630-031P

FASTENING SYSTEM

The baseline fastening method for this experiment is induction fastening. This process oscillates at high frequency a magnetic field which is in close proximity to a metallic grid. The tool shown in subsequent drawings was designed at Langley Research Center. A development version of the tool was evaluated at Grumman Aerospace Corporation concurrently with this study.

The tool has several advantages which led to its selection as the baseline. Since it applies energy only to the region that needs to be heated (the wire mesh is surrounded by a thermoplastic material), it only consumes a small amount of power – less than 100 watts per spot. The tool is also relatively small. However, it was found to have the problems shown on the facing page. Consequently, if these deficiencies are not corrected, another fastening method will be incorporated into the flight experiment. The prime candidate for a replacement fastening method is ultrasonic welding, which has been successfully used to fasten thermoplastic materials.

FASTENING SYSTEM

- BASELINE TOOL: LaRC INDUCTION FASTENING TOOL
- PROBLEMS
  - TOOL IS NOT READY FOR PRODUCTION TYPE USE. FREQUENT TOOL STRUCTURAL FAILURES WERE ENCOUNTERED DURING GRUMMAN TEST PROGRAM
  - TOOL HAS NOT BEEN OPTIMIZED FOR USE ON HIGH TEMPERATURE THERMOPLASTICS
    - 2 MINUTE FASTENING TIME FOR GR/PES IS UNSATISFACTORY FOR PRODUCTION BEAM BUILDERS
- ALTERNATE FASTENING SYSTEM
  - ULTRASONIC WELDING

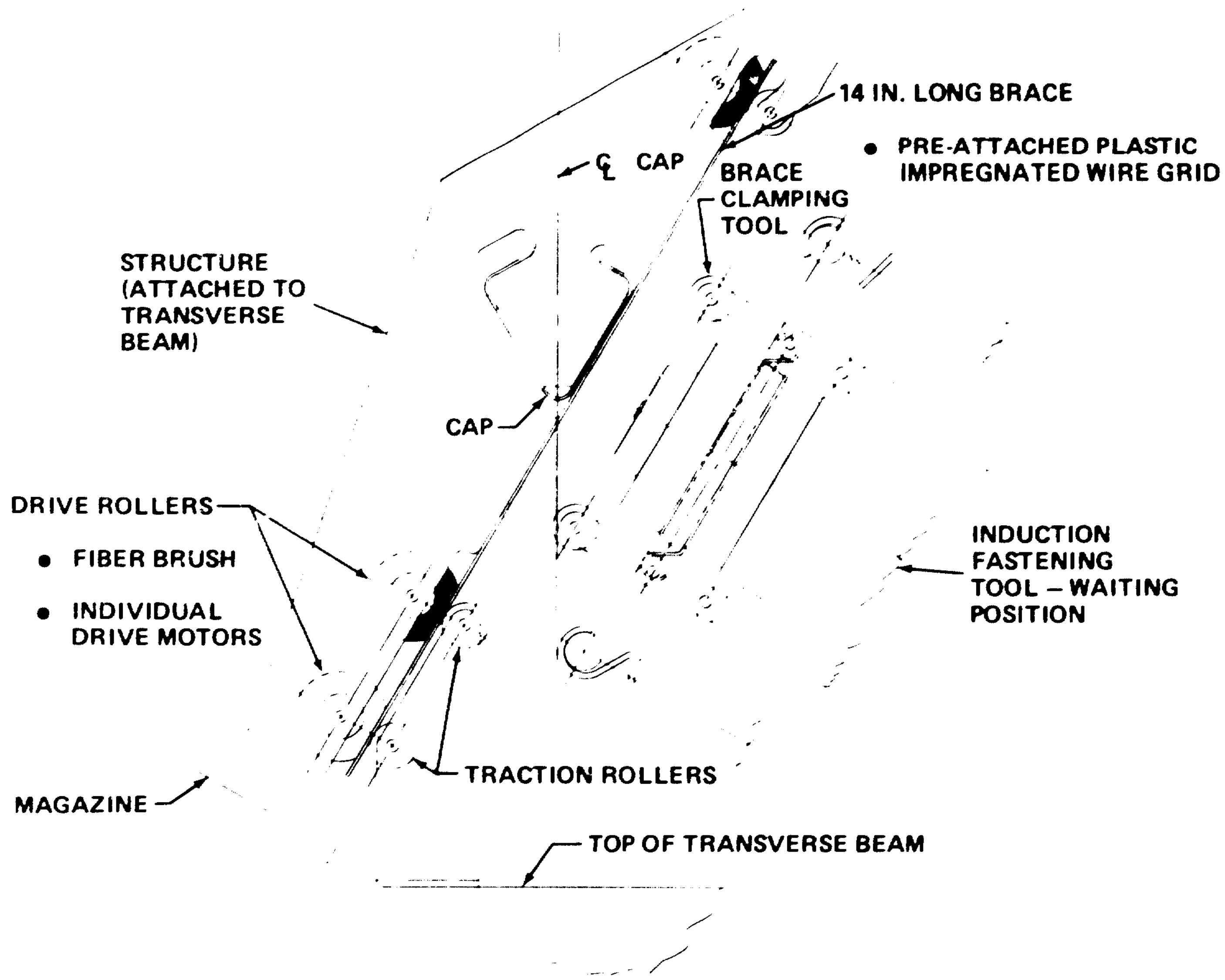
GRUMMAN

BRACE RETENTION BY DISPENSING SYSTEM

As a brace emerges from the magazine's transfer shelf, it is guided by shelf geometry and orientation into the 2 pairs of drive-rollers/traction-rollers shown in the lower left region of the drawing. These pairs of rollers provide brace guidance (within the plane of the paper) and translation forces after the brace has left the lipped transfer shelf. They continue to impel the brace until it reaches the position shown on the facing page, where it is stopped by the structure in the upper right region. The friction forces developed by deflected fibers on 3 drive rollers provide the only restraint on brace motion into and out of the paper. This "soft" restraint is necessary to permit cap and brace translation into the paper after a brace has been fastened to a cap.

To prevent the induction fastening tool from moving the brace as it comes into brace contact for forming the first spot, two brace clamping tools are used. These tools, which surround the fastening tool symmetrically and are attached to it, apply forces through a brace and into the structure to the left of the brace. Rollers on the end of a clamping tool prevent the build up of forces which are tangential to the brace. The rollers also permit continuous high friction clamping forces while the induction fastening tool moves through its final motions and contacts the brace.

BRACE RETENTION BY DISPENSING SYSTEM



ORIGINAL PAGE IS
OF POOR QUALITY

V82-0630-023P

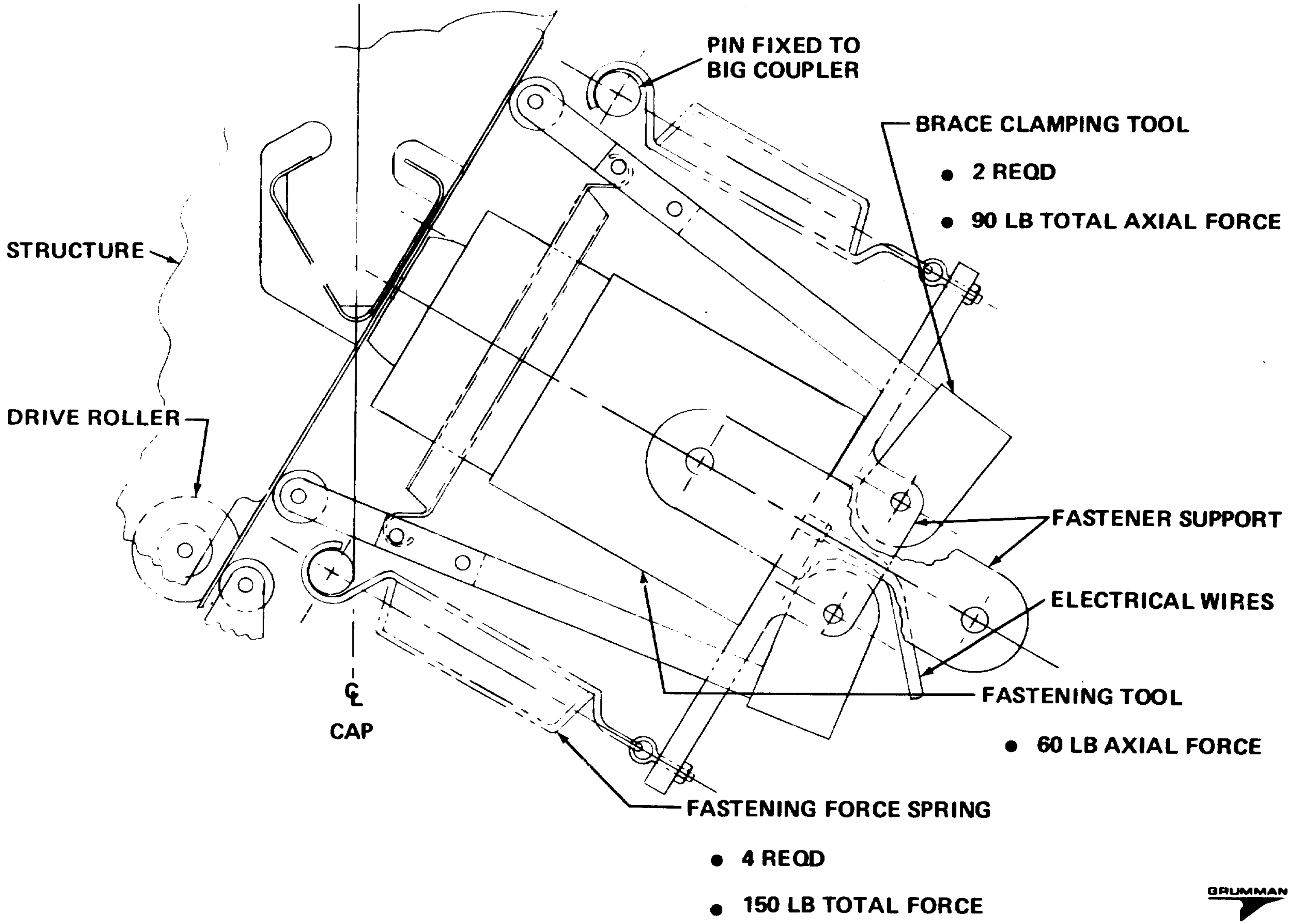
FASTENING LOWER SPOT

Each roller of a brace clamping tool applies 45 pounds of compression to a brace. This level of force (90 lb total) should be adequate to prevent the brace from moving under the impact of a possibly misaligned fastening tool with 60 pounds (maximum) of spring force behind it.

The forces applied to a brace by the brace clamping tool and the fastening tool are developed by spring systems. This is done to ensure repeatability and control over the force applied to a brace during fastening. Weld quality is significantly influenced by fastening force magnitude.

The induction fastening tool is attached at one end to the fastener support, which also supplies pivots for the brace clamping tools. The fastener support is always pulled toward the cap by 4 fastening force springs. This spring force is reacted by 2 pins which are cantilevered off a large structure called big coupler. Both big coupler and the fastener support are coupler links in 4 bar parallelogram linkages.

FASTENING LOWER SPOT



GRUMMAN

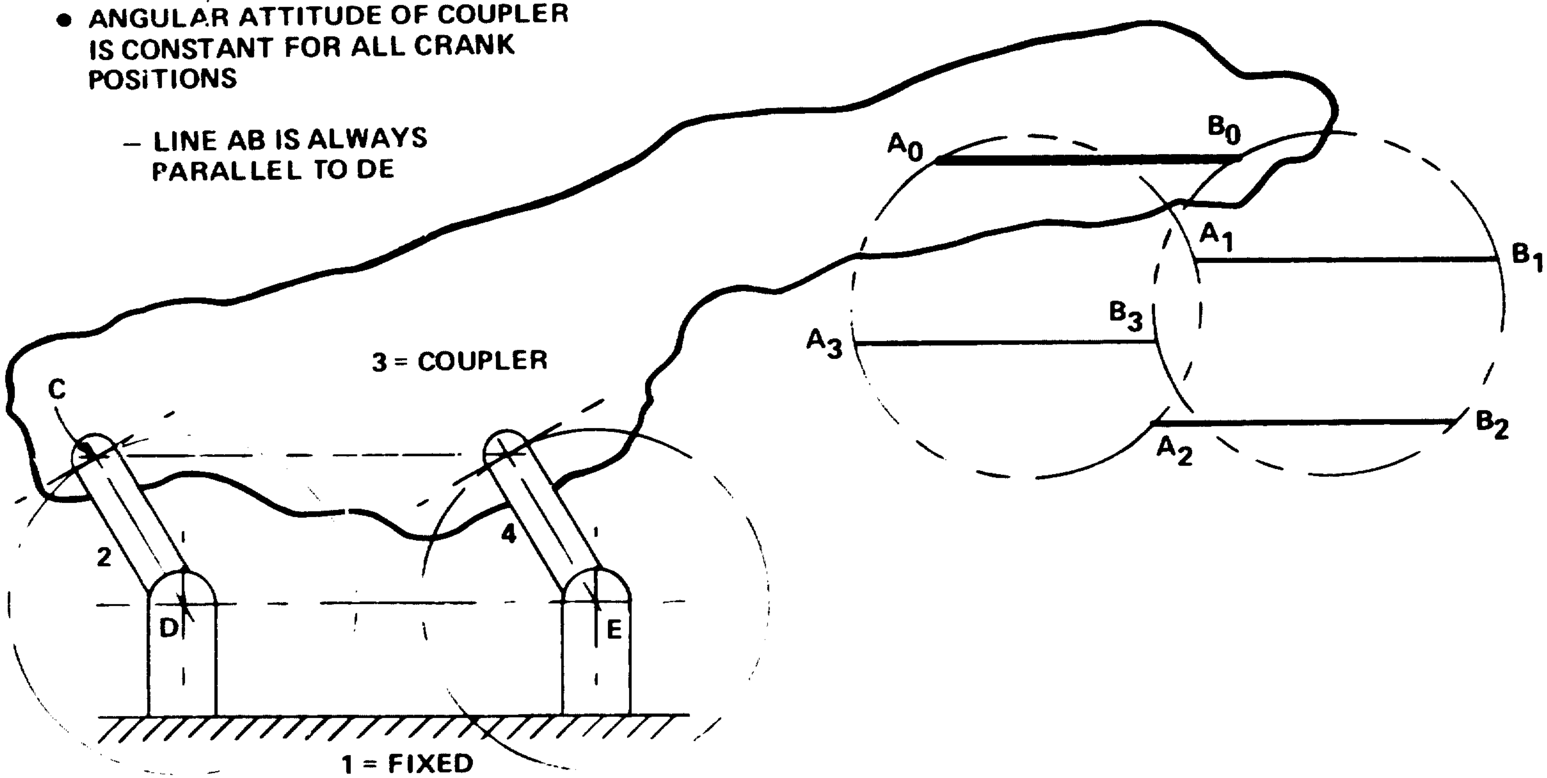
V82-0630-024P

PARALLELOGRAM LINKAGE

A parallelogram linkage has 2 equal length cranks (links 2 and 4 in the diagram) that are parallel to each other. As they rotate, the line connecting the cranks to the coupler (the horizontal line starting at C) remains parallel to the line connecting the cranks to the fixed link (line DE). All points on the coupler link move on a similar path: a circular path of radius DC whose center has the same angular relation to the point as D has to C. For example, for clockwise rotation of the cranks, point A (on the coupler) moves along the circle A_0, A_1, A_2, A_3, A_0. Since this is true for all points (like B_0, B_1, B_2, B_3, B_0), any line on the coupler (like A_0 B_0) maintains the same angular relationship tothe fixed link (DE) for all positions of the cranks. In this example, A_i B_i is always parallel to DE.

PARALLELOGRAM LINKAGE

- ALL POINTS ON COUPLER LINK MOVE ON SIMILAR PATHS
  - POINTS A & B DUPLICATE MOTION OF POINT C
- ANGULAR ATTITUDE OF COUPLER IS CONSTANT FOR ALL CRANK POSITIONS
  - LINE AB IS ALWAYS PARALLEL TO DE



V82-0630-022P

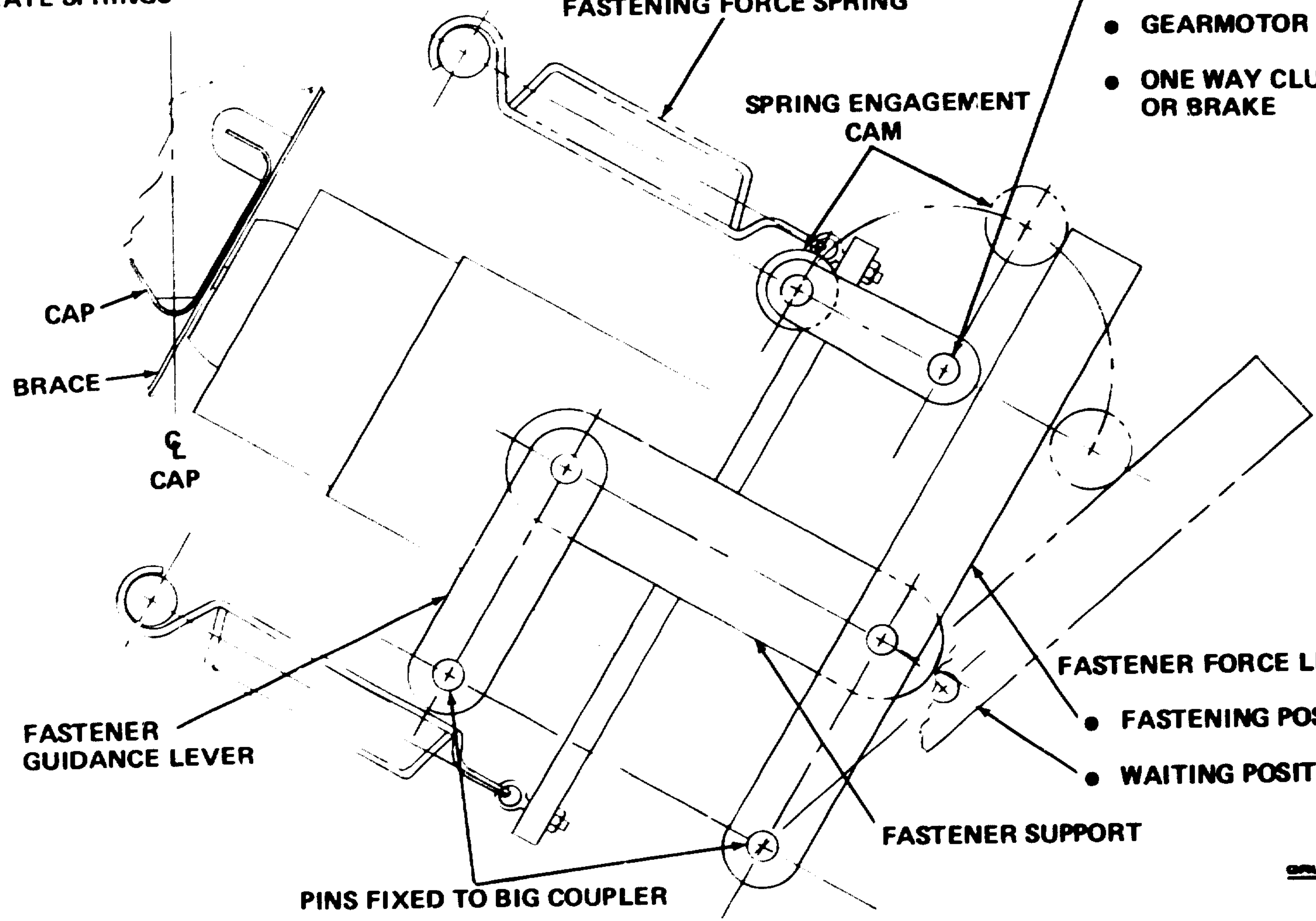
FASTENING FORCE CONTROL

The fastener support (coupler) is attached to two cranks, the fastener guidance lever on the left and the fastener force lever on the right. Both cranks are attached to the fixed link (big coupler = link 1) by their lower pivots. The drawing on the facing page shows the fastening force springs in their least extended position, with the fastening tool reacting to the spring forces through the brace.

To move the fastening tool from the position shown to the waiting position shown on page 59, a motor driven shaft (which is supported on big coupler) rotates the spring engagement cam clockwise (see upper right of facing page). The first 90° of rotation doesn't effect anything. At 90°, the spring engagement cam begins to push the fastener force lever to the right. After 130° of spring engagement cam rotation, the fastener force lever (and fastening tool) have reached the waiting position. The spring engagement cam drive motor is stopped and locked in this position.

FASTENING FORCE CONTROL

- AMPLE CONTROL OVER FASTENING FORCES OBTAINED WITH LOW SPRING RATE SPRINGS



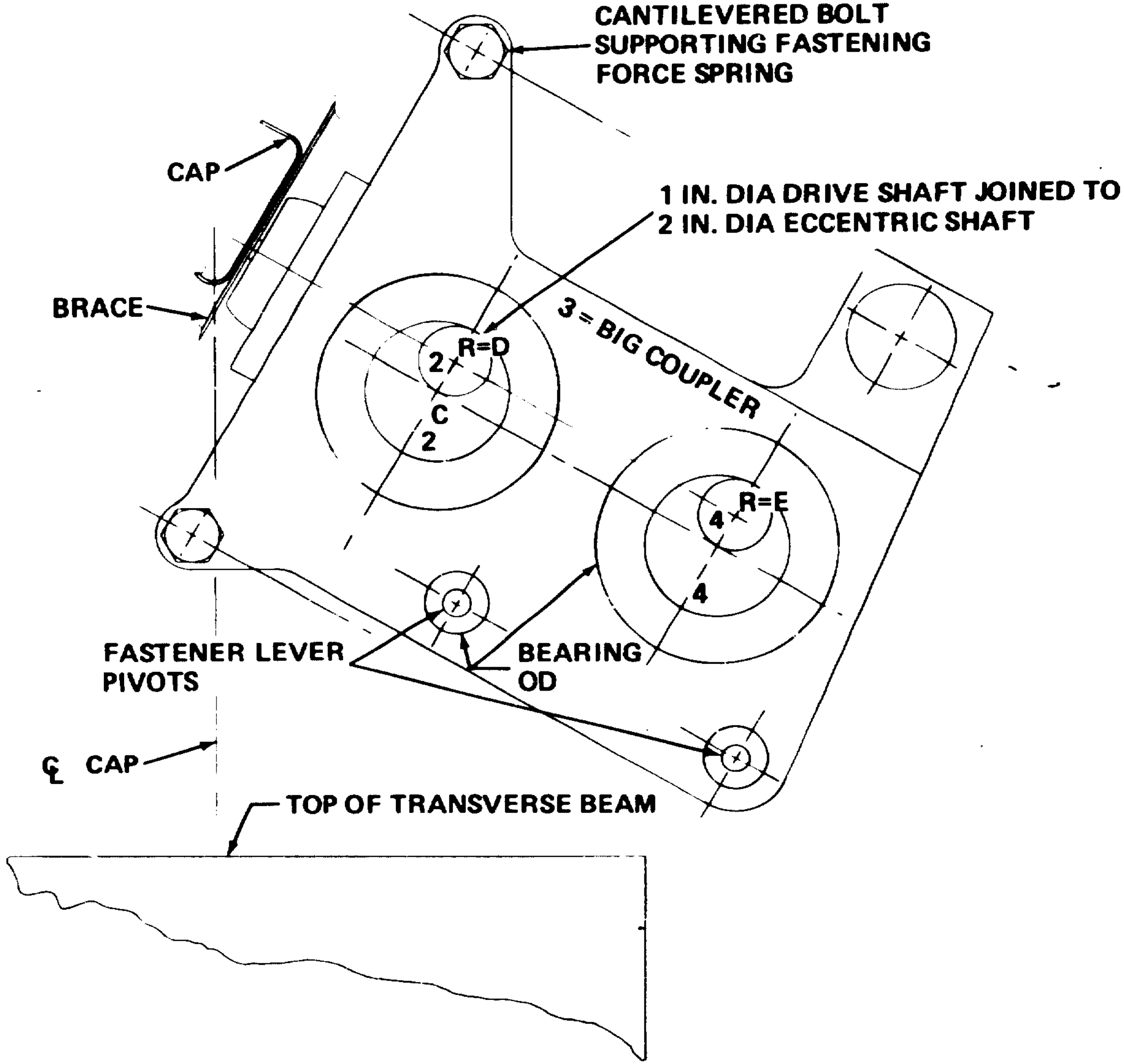
V82-0630-025P

BIG COUPLER, LOWER FASTENING POSITION

The preceeding pages described fastening tool motion control to and from the cap surface (i.e., motions normal to the cap's fastening surface). The next few pages will describe the required motion control in going from the lower spot to the upper spot position (i.e., motion parallel to the cap's fastening surface).

Big coupler is a fixed link for supporting fastener tool motions normal to the cap. The small bearings shown near the bottom of big coupler provide the rotational degree of freedom for that motion. However, with the fastening tool in its waiting position, big coupler moves from the position shown on the facing page to the position shown on the following diagram. This is achieved by rotating two cranks (links 2 & 4 on the facing page) through 180°. To improve rigidity and compactness of this mechanism, the cranks were made as short as possible: a 1 inch diameter shaft eccentrically machined from a 2 inch diameter shaft. Since there is relative rotation between the cranks and coupler, the 2 inch diameter shafts are supported by ball bearings in big coupler. The center of these bearings, C, is offset 1/2 inch from the center of shaft rotation, R. Points R correspond to points D & E on links 2 & 4, respectively, on page 63. Points R are fixed in space since the 1" diameter shaft is supported by structure (big coupler support – page 71) which is attached to the transverse beam.

BIG COUPLER, LOWER FASTENING POSITION

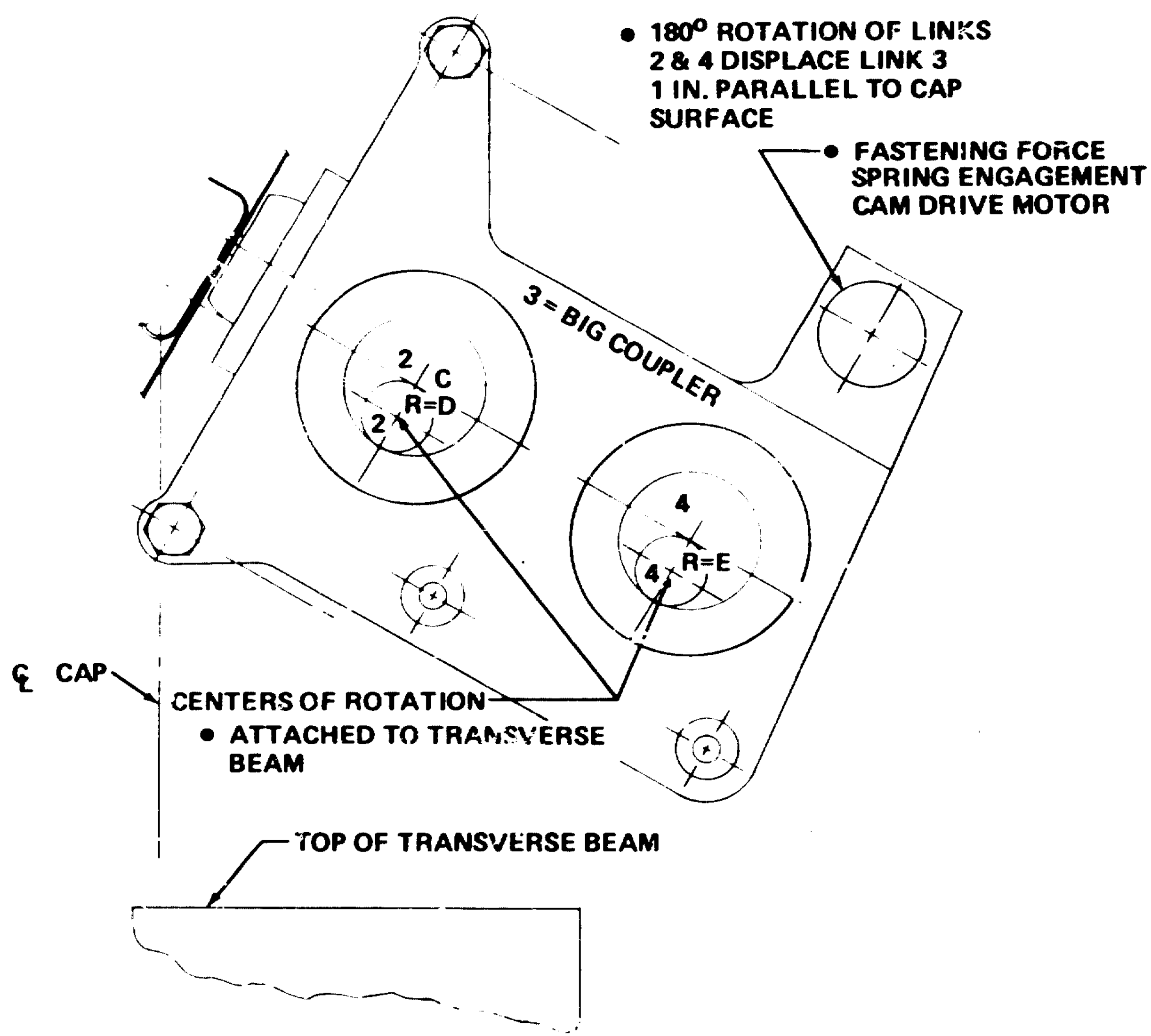


V82-0630-026P

BIG COUPLER, UPPER FASTENING POSITION

The facing page shows the position of big coupler after a 180° rotation of the eccentric shafts (links 2 & 4). This is the position for fastening the upper spot on a brace.

BIG COUPLER, UPPER FASTENING POSITION

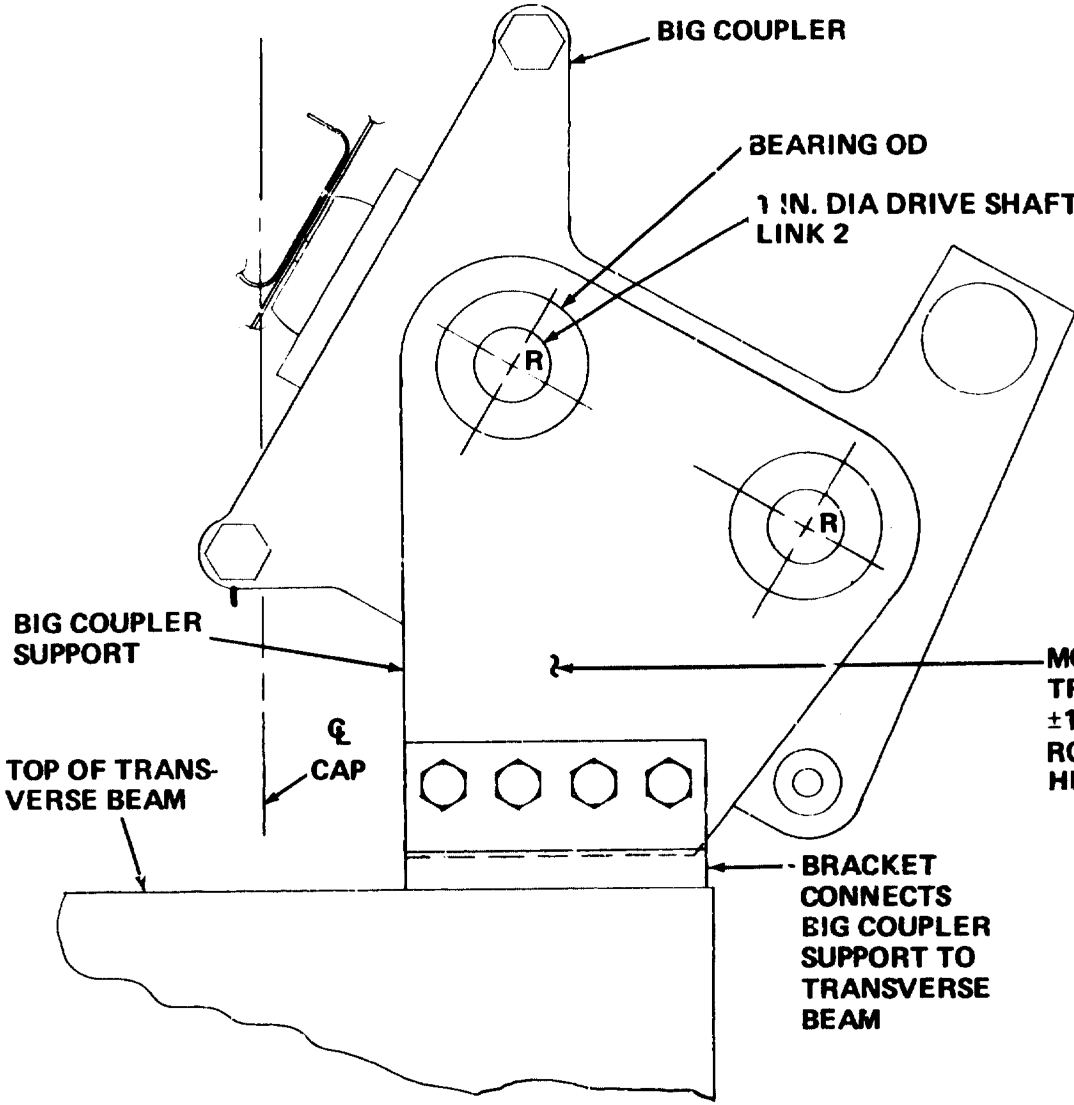


V82-0630-027P

BIG COUPLER SUPPORT

The drawing on the facing page shows the structural support for the fastening system. Forces from the brace are transmitted through big coupler to big coupler support via the 1 inch diameter drive shafts. A bracket with 4 bolts then transmits these forces to a major structural element of the flight experiment, the transverse beam.

BIG COUPLER SUPPORT



GRUMMAN

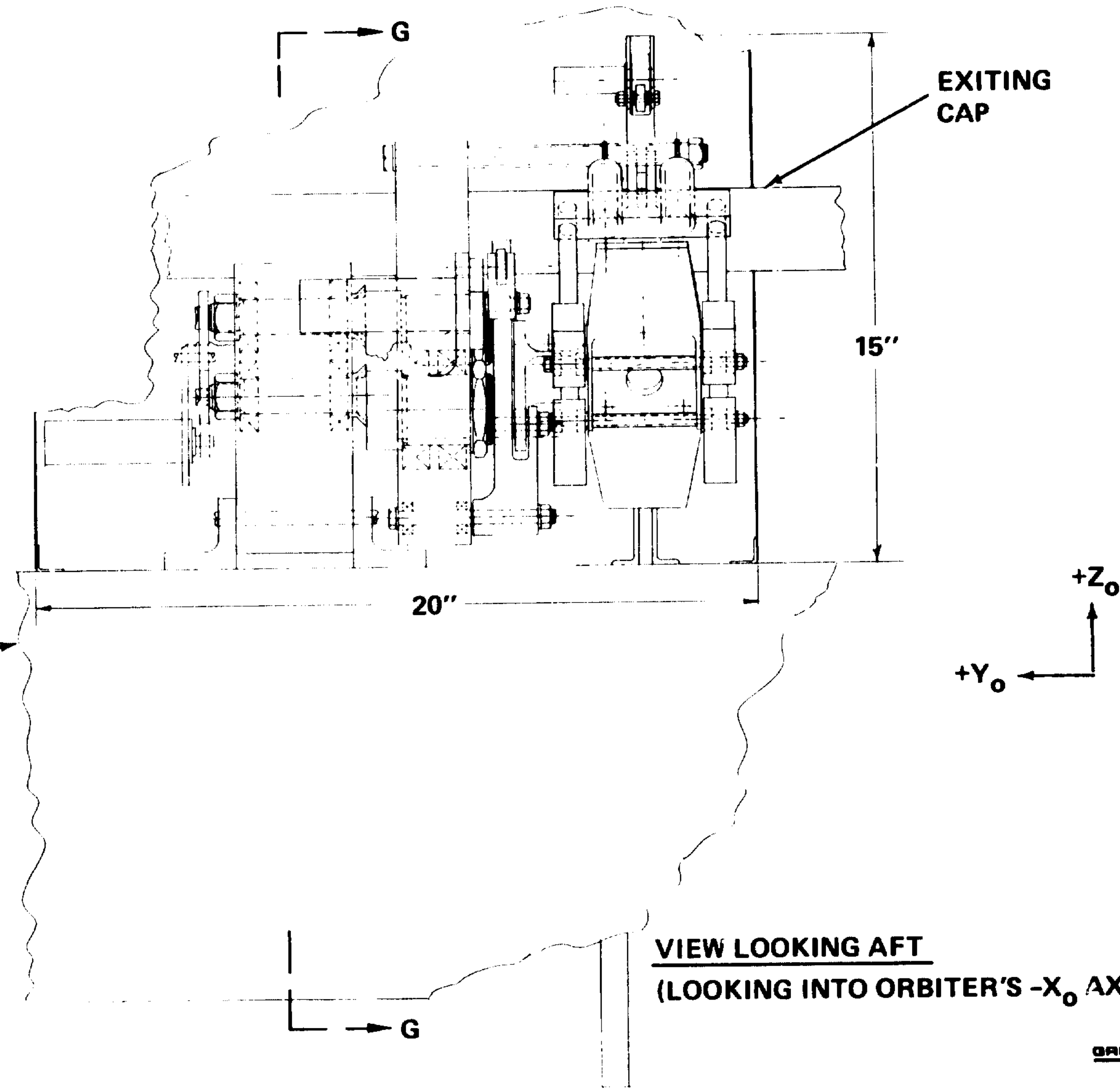
V82-0630-028P

FASTENING SYSTEM LAYOUT

This drawing provides an orthogonal view of the general arrangement of the components which were described on the preceeding 7 drawings. The fastening system occupies a volume which is 15 inches above the upper surface of the transverse beam and 20 inches along its length (parallel to cap longitudinal axis).

View GG (shown on the following drawing) looks at the fastening system from the same perspective as the preceeding 7 drawings.

FASTENING SYSTEM LAYOUT



VIEW LOOKING AFT
(LOOKING INTO ORBITER'S $-X_o$ AXIS)

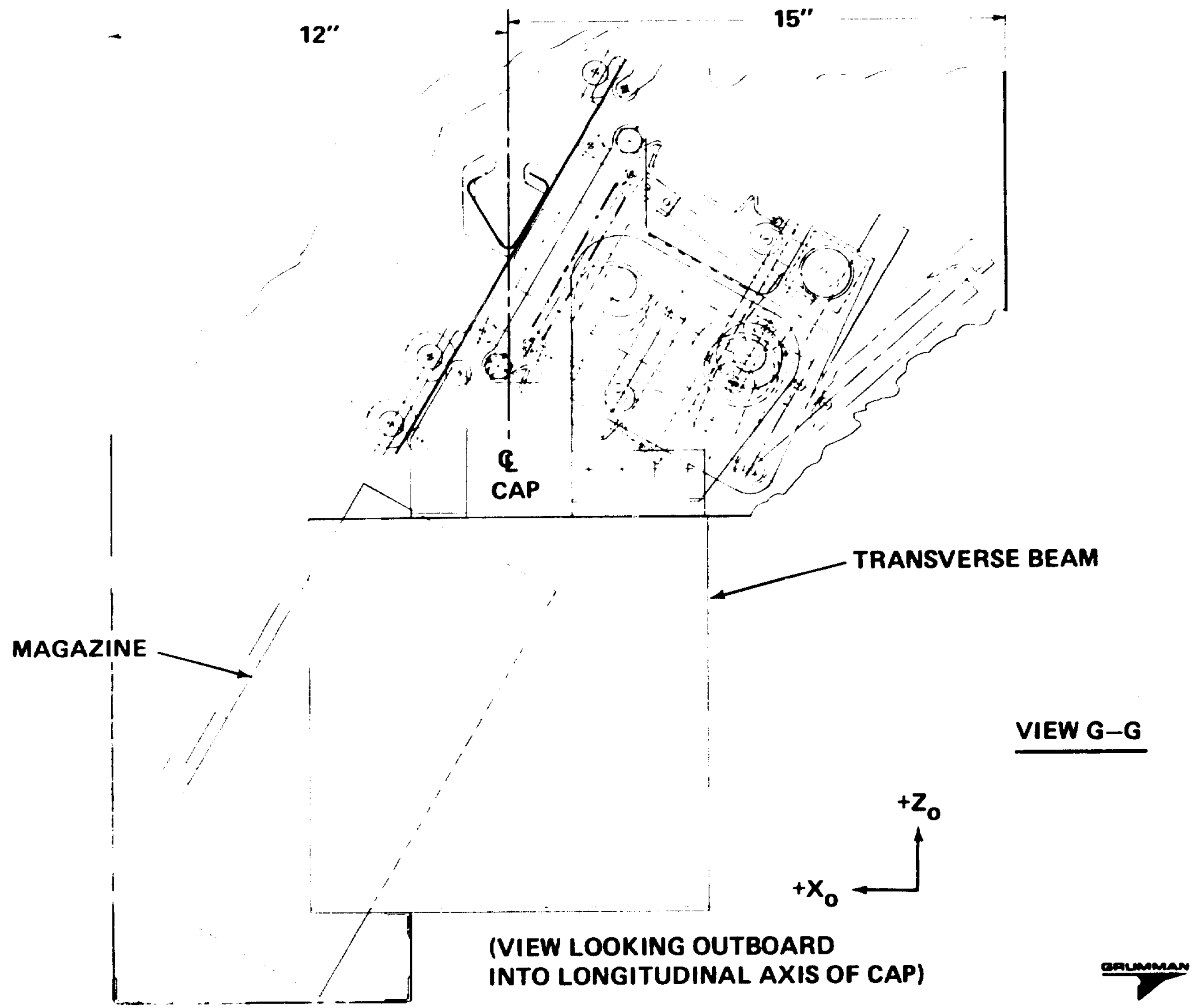
GRUMMAN

1230-014B

FASTENING SYSTEM LAYOUT (CONTD)

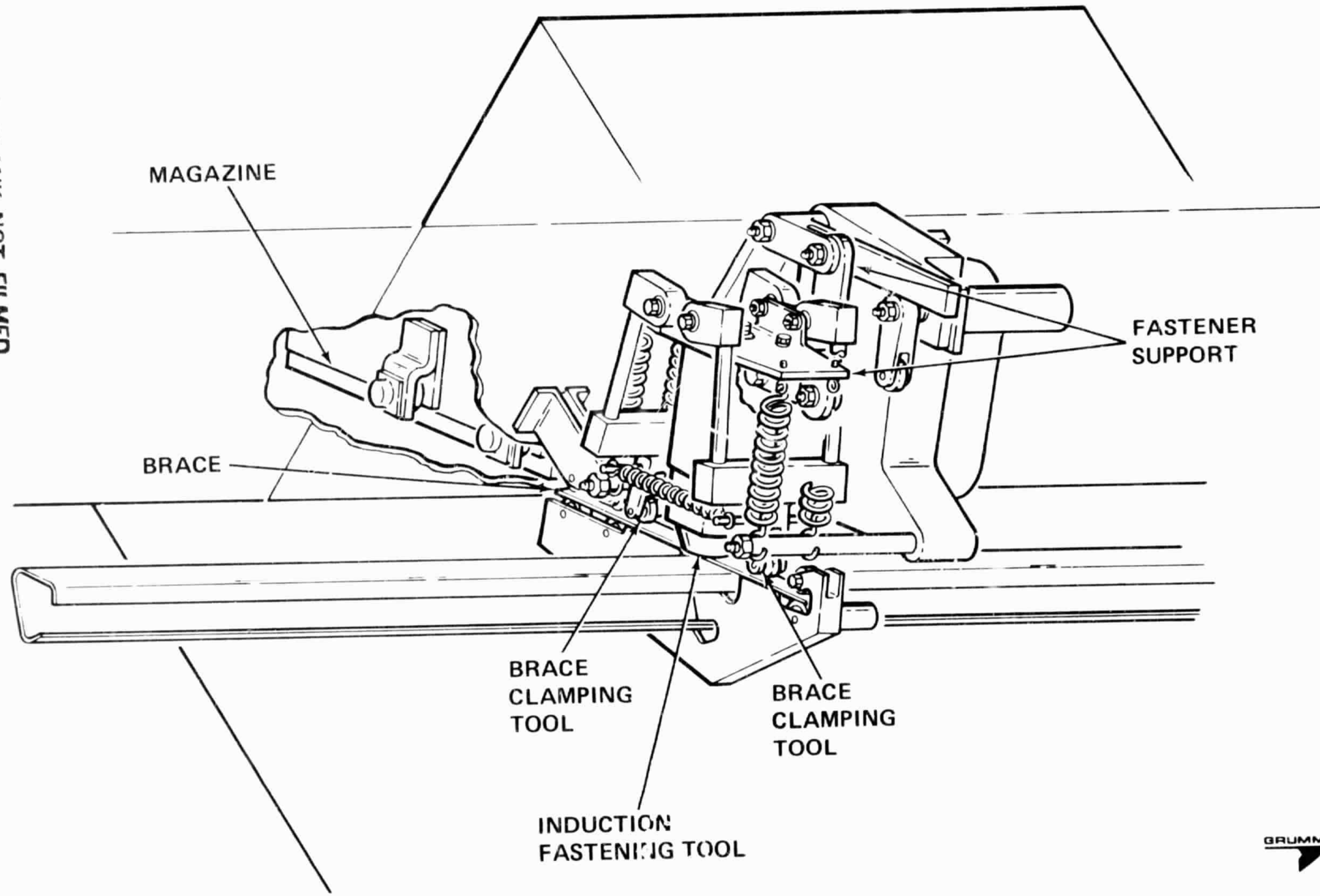
This general arrangement view shows the relationship of all the components of the fastening system to the other relevant major structural and mechanical systems of the flight experiment. The fastening system extends from 12 inches aft of the cap centerline to 15 inches forward of it. The Orbiter coordinate system is shown in the lower right portion of the figure.

FASTENING SYSTEM LAYOUT (CONT)



1230-013B

FASTENING ISOMETRIC



1230-011B

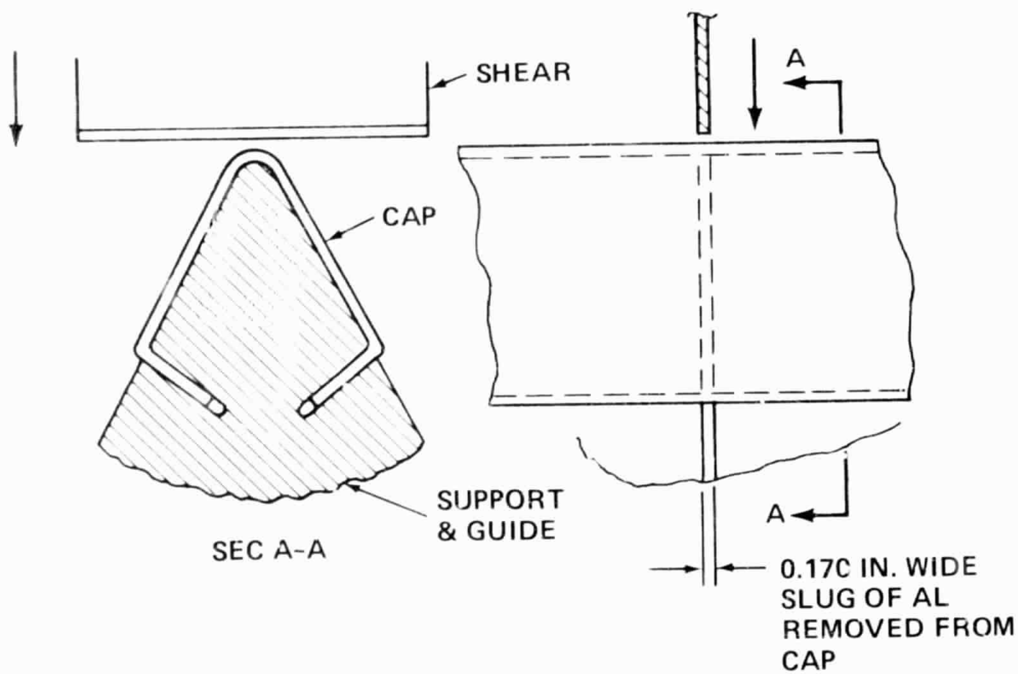
PAGE 74 INTENTIONALLY BLANK

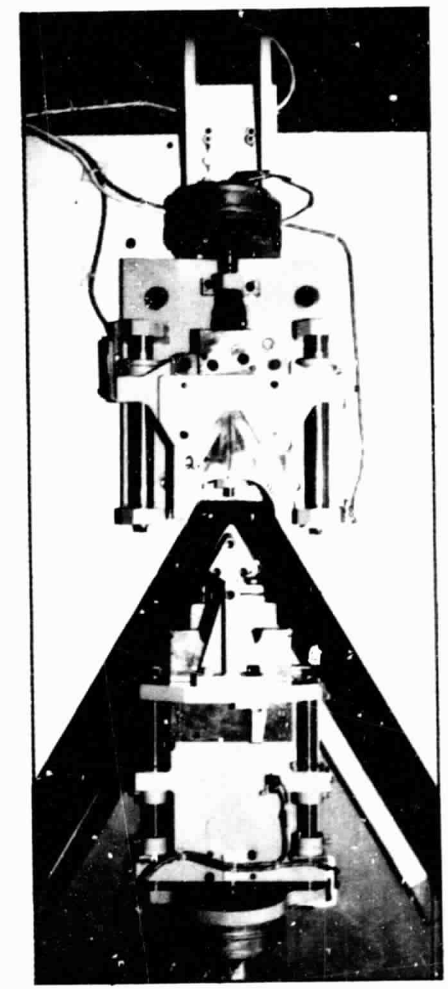
CAP CUTOFF SYSTEM

GUILLOTINE FROM ALIMINUM BEAM BUILDER

The dual requirements of producing a length of cap long enough to exercise the fabrication machinery plus the need to limit cap length to 15 feet or less imply a need for a method of cap cutting. The system shown on the facing page is used for the Aluminum Beam Builder (ABB). Since this type of device is part of Beam Builder technology, it was chosen as the cutoff system for this flight experiment. However, it is known from some experiments conducted several years ago that the relatively wide flat blade used on the ABB guillotine is unsatisfactory for cutting composite materials. Consequently, new guillotine blade designs will have to be developed for composite caps.

CAP CUTOFF SYSTEM
GUILLOTINE FROM ALUMINUM BEAM BUILDER





PROBLEM FOR COMPOSITE CAP

- EXPERIMENT ON GR/ACRYLLIC CAP PRODUCED FRAYED ENDS ON BOTH PIECES OF CAP. REMOVED "SLUG" OF MATERIAL WASN'T SOLID PIECE: BROKEN INTO MANY PIECES & LOOSE FIBERS

GRUMMAN

V82-0630-008P

CAP CUTOFF SYSTEM RECOMMENDATIONS

The major recommendations for a guillotine system for composite caps are as follows:

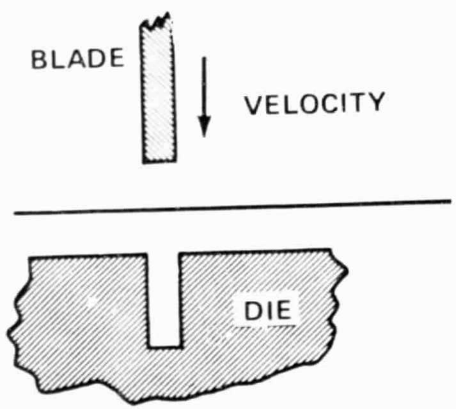
- use sharp cutting edges
- provide a container to trap large pieces cut from cap
- experiment with different blade shapes to determine one that could be used for production beam builders

CAP CUTOFF SYSTEM RECOMMENDATIONS

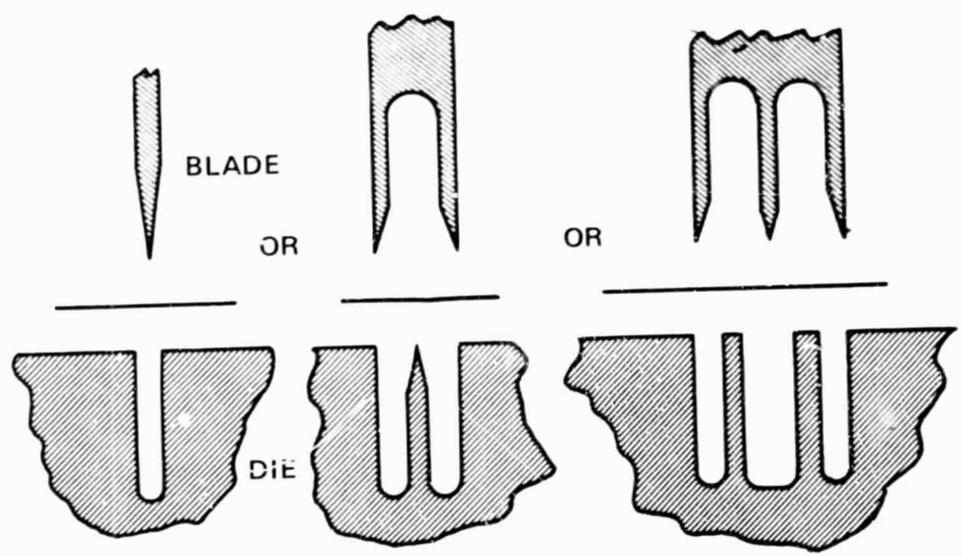
- USE EXISTING AL BEAM BUILDER GUILLOTINE AS BASIS FOR ROM WEIGHT & COST (PRODUCTION) ESTIMATES

  WEIGHT = 155 LB (EXISTING) + 5 LB (PARTICLE CONTAINMENT) + 10 LB (NEW BLADE DESIGN) = 170 LB

- REDESIGN BLADE TO PROVIDE CUTTING ACTION RATHER THAN PUNCHING ACTION



EXISTING DESIGN



CANDIDATE COMPOSITE CAP GUILLOTINE BLADE CROSS-SECTIONS

- PROPER BLADE DESIGN REQUIRES EVALUATION BY TESTING

ORIGINAL PAGE IS OF POOR QUALITY

GRUMMAN

V82-0630-017P

CONTAMINATION CONTROL: SOLID PARTICLES

The facing page contains a preliminary overview of the techniques chosen for containment and capture of solid particles. Some of these methods have been altered by later developments in the study. Two changes in particular are noted here:

- the roll forming and fastening regions are no longer fully enclosed. Chimney vents have been provided to vent gasses
- high voltage is not required for an electrostatic tunnel system. The Orbiter's power supply provides ample e.m.f. (28 VDC).

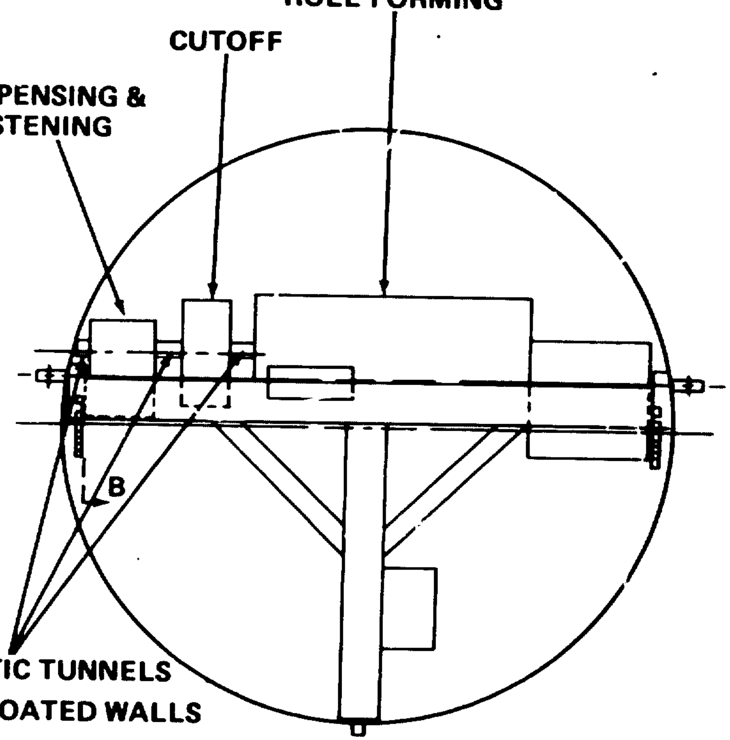
The largest quantity of solid particles are expected in the cutoff system. Consequently, the major emphasis on control was in these regions. As shown, the region is surrounded on both sides by electrostatic tunnels. The diagram on the following page shows some features used to design these tunnels.

CONTAMINATION CONTROL: SOLID PARTICLES

- SEAL ENTRANCE & EXIT OF PROCESS REGIONS WITH BRUSHES
  - -- WIPE CAP ON INSIDE & OUTSIDE
  - -- WIPE BRACE ON BOTH SIDES
  - – STOP ALL PARTICLES LARGER THAN TBD

- CAPTURE SMALL (& SOME BIG) PARTICLES WITH ELECTROSTATICALLY CHARGED TUNNELS
  - – CAP ELECTRICALLY CONNECTED TO HIGH VOLTAGE (LOW POWER) DC SOURCE
  - – BROKEN PARTICLES HAVE SAME POLARITY AS CAP (AND MACHINE)
  - – PARTICALS ATTRACTED TO OPPOSITELY CHARGED TUNNEL WALLS
  - – ADHESIVE ON TUNNEL WALL RETAINS PARTICLE AFTER CAPTURE
    - ADHESIVE FORCES MUST EXCEED ELECTROSTATIC FORCES

- EXAMINE BRUSHES & TUNNEL WALLS ON RETURN TO EARTH



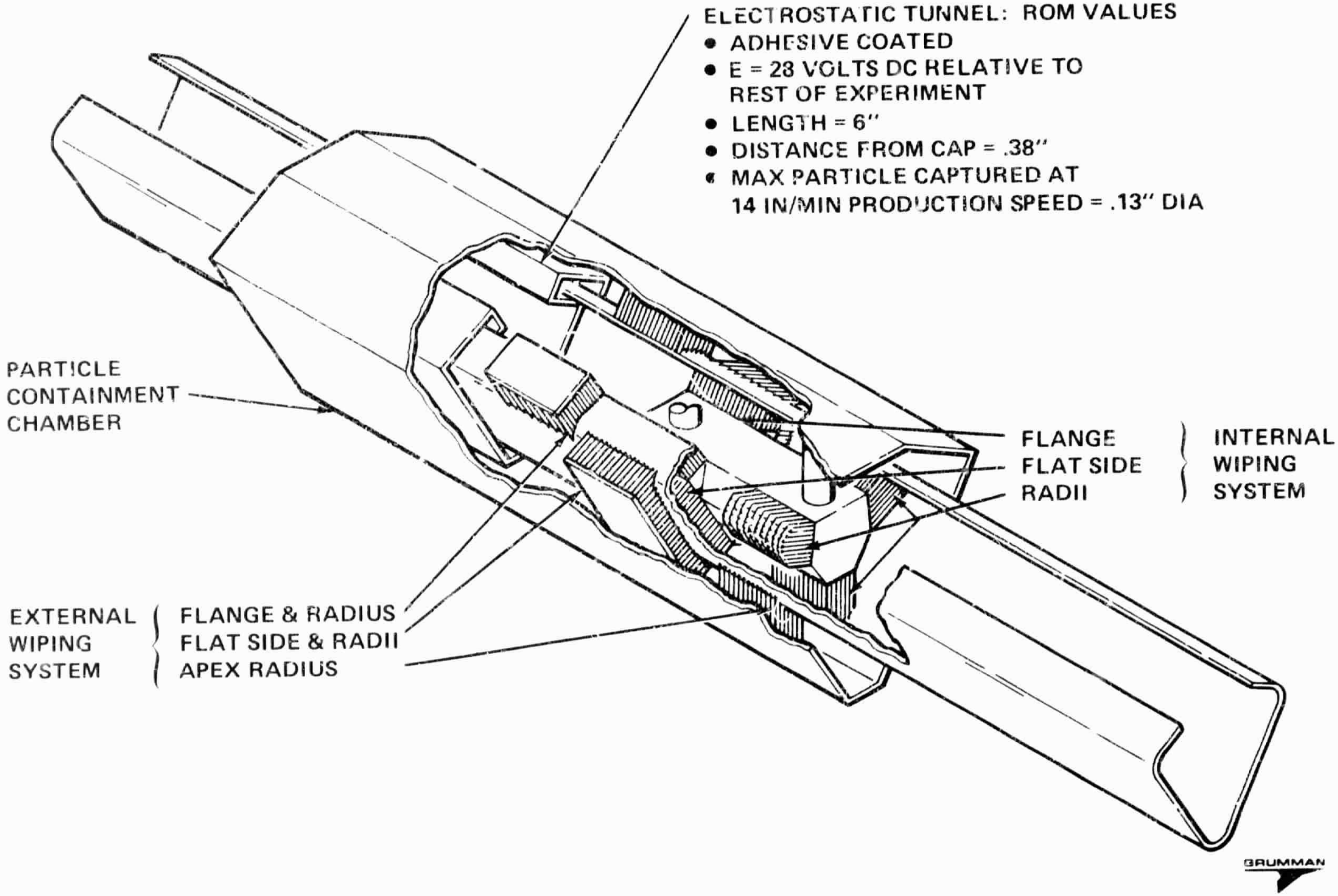
GRUMMAN

V82-0630-041P

SOLID PARTICLE CONTAINMENT

The drawing shows some details of how solid particles will be controlled and contained on the flight experiment. The completely closed particle containment chamber connects on both ends to the containers of the adjacent processes. Particles enter or exit from the chamber through the opening for the cap at each end. Inside the particle containment chamber, extending for 6 inches, is an electrostatic tunnel. The walls (both internal and external) are covered with adhesive. The tunnel is approximately parallel to the exterior and interior surfaces of the cap, separated by 3/8 in. The cap and all machine components that come into contact with it (e.g., rolling mill, guillotine, guides, etc.), are maintained at one electrostatic polarity (+ or –). The electrostatic tunnel is maintained at the other polarity with 28 VDC between the cap and tunnel. At a cap velocity of 14 inches/minute, the 28 volts is sufficient to pull a zero normal velocity, 1/8 inch dia PES particle off the surface of a cap and into the adhesive before the particle leaves the tunnel. Smaller particles get captured much sooner as do conductive particles. At the tunnel end farthest from the cutoff system, a system of brushes are attached to the inside of the particle containment chamber. These brushes wipe the entire exterior surface of the cap. Another set of brushes, attached to a structure suspended in the cap interior, wipe all interior surfaces of the cap. Brushes can be arranged to form a flexible porous seal of the opening through which the cap passes, trapping all large particles within the cutoff region.

SOLID PARTICLE CONTAINMENT



1230-009B

CONTAMINATION CONTROL: GAS PARTICLES

The amount of gas produced by the CBCF and the subsystems is unknown at this time. Some of the ground testing of the CBCF has produced visible gasses. These have been attributed to oxidized thermoplastic which resulted from excessive lamp heat. Other ground tests have produced no visible gas. At a minimum, adsorbed gas molecules on the surface of the heated regions will be released in space. To accommodate all possible quantities of gaseous emissions, the flight experiment has been designed to vent all gasses overboard, away from the payload bay and other experiments.

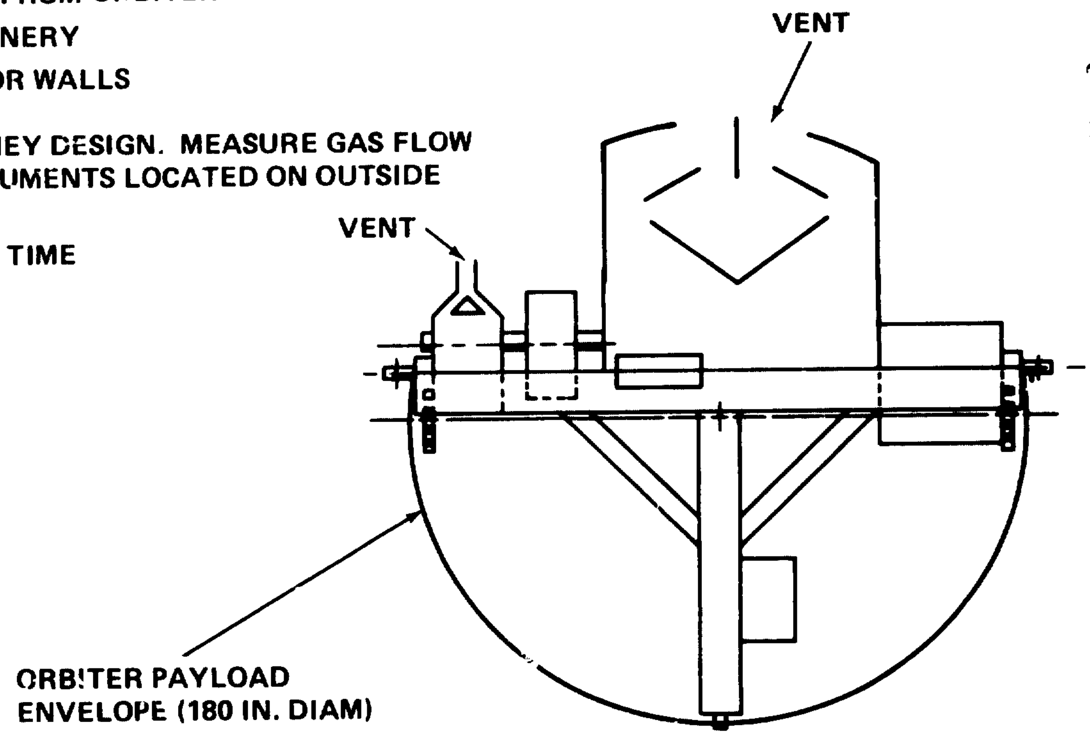
The chimneys contain baffles to prevent direct sunlight from entering a vent and locally heating the fabrication machinery or a cap. The design shown on the facing page was developed early in the study. Configurations shown elsewhere (see pages 119 & 125) in this report use a chimney whose vent is closed for reentry. A dry nitrogen bottle and valves maintain a small ΔP between pressure within the system containers and payload bay ambient. This prevents reentry air from adding dirt to the interior adhesive walls and distorting a post-flight data base.

Special lip designs may be required for the fastening system chimney to prevent gas flow into the payload bay. Assurance that the design techniques chosen are effective in preventing payload bay contamination will be provided by 10 quartz microbalance instruments located on various exterior surfaces of the flight experiment. These instruments will record the time history of mass accumulation of the surfaces. The effects of this flight experiment will be obtained by comparing the microbalance time histories compiled during and immediately after the CBCF flight experiment with those recorded before and long after experiment activity.

CONTAMINATION CONTROL: GAS PARTICLES

- GASES WITH HIGH VAPORIZATION TEMPERATURE
  - CONDENSE ON WALLS OF 70°F ENCLOSURE & MACHINE & SOLIDIFY
- GASES WITH LOW VAPORIZATION TEMPERATURES
  - MOLECULES BOUNCE AROUND INTERIOR OF ENCLOSURE UNTIL THEY ESCAPE THROUGH "VENT" OR BRUSH SEAL
- USE BAFFELED CHIMNEYS TO DIRECT FLOW OUT OF PAYLOAD BAY
  - OPEN END (VENT) POINTS AWAY FROM ORBITER
  - NO DIRECT SUNLIGHT ON MACHINERY
  - HIGH ABSORBTIVITY (α) INTERIOR WALLS
- VERIFY EFFECTIVENESS OF CHIMNEY DESIGN. MEASURE GAS FLOW RATE WITH MICROBALANCE INSTRUMENTS LOCATED ON OUTSIDE OF EXPERIMENT
  - RECORD MASS OF PARTICLES VS TIME

ORIGINAL PAGE IS OF POOR QUALITY



TYPICAL BAFFELED CHIMNEYS

1230-032B

ELECTRICAL/ELECTRONIC DESIGN

The quality of definition of the electronic system is very high since many of the needed components are in production for other programs. The microprocessor and power controller use hardware that is being developed for other programs at Grumman. Most of the other hardware has been qualified for space use by other suppliers.

ELECTRICAL/ELECTRONIC DESIGN

- PRELIMINARY DESIGN BY PEOPLE WHO DID THERMAL CANNISTER
  - BOB Mc ELHINEY & JERRY STEPHENS
- GRUMMAN DESIGNED SPACE QUALIFIED MICROPROCESSOR CONTROLLER
  - CURRENTLY UNDER DEVELOPMENT ON FORWARD SWEPT WING AIRCRAFT
  - Z80 CHIP, 1K RAM (EXPANDABLE TO 17K), 8K ROM, 2 CHANNELS RS 232, INTERRUPT DRIVEN INPUT/OUTPUT, COMMAND INTERPRETATION & EXECUTION, TIME OF DAY CLOCK MAINTENANCE
  - 15 LB, 50 WATTS, 4 1/2 X 10 X 8 1/2 IN.
- POWER CONTROLLER
  - 22 LB, 25 WATTS, 4 1/2 X 10 X 8 1/2 IN.
- PULSE COUNT MODULATION SYSTEM
  - BASE TEN SYSTEMS P/N 7-154
  - 8 LB, ~ 20 WATTS, 7 X 7 X 6 IN.
- TAPE RECORDER
  - LOCKHEAD P/N 4200
  - 6 LB, 15 WATTS, 6 X 8 X 4 IN.
  - BORROW → DO NOT BUY
- INVERTER (2 REQUIRED)
  - AEROSPACE AVIONICS NUMBER TBD
  - 55 LB, 80% EFFICIENCY, 19 x 8.5 x 8.5 IN.
- INDUCTION FASTENER POWER SUPPLY
  - 13 LB, 100 WATTS
- MAX POWER CONSUMPTION FROM ALL SOURCES ~ 2.7 KW

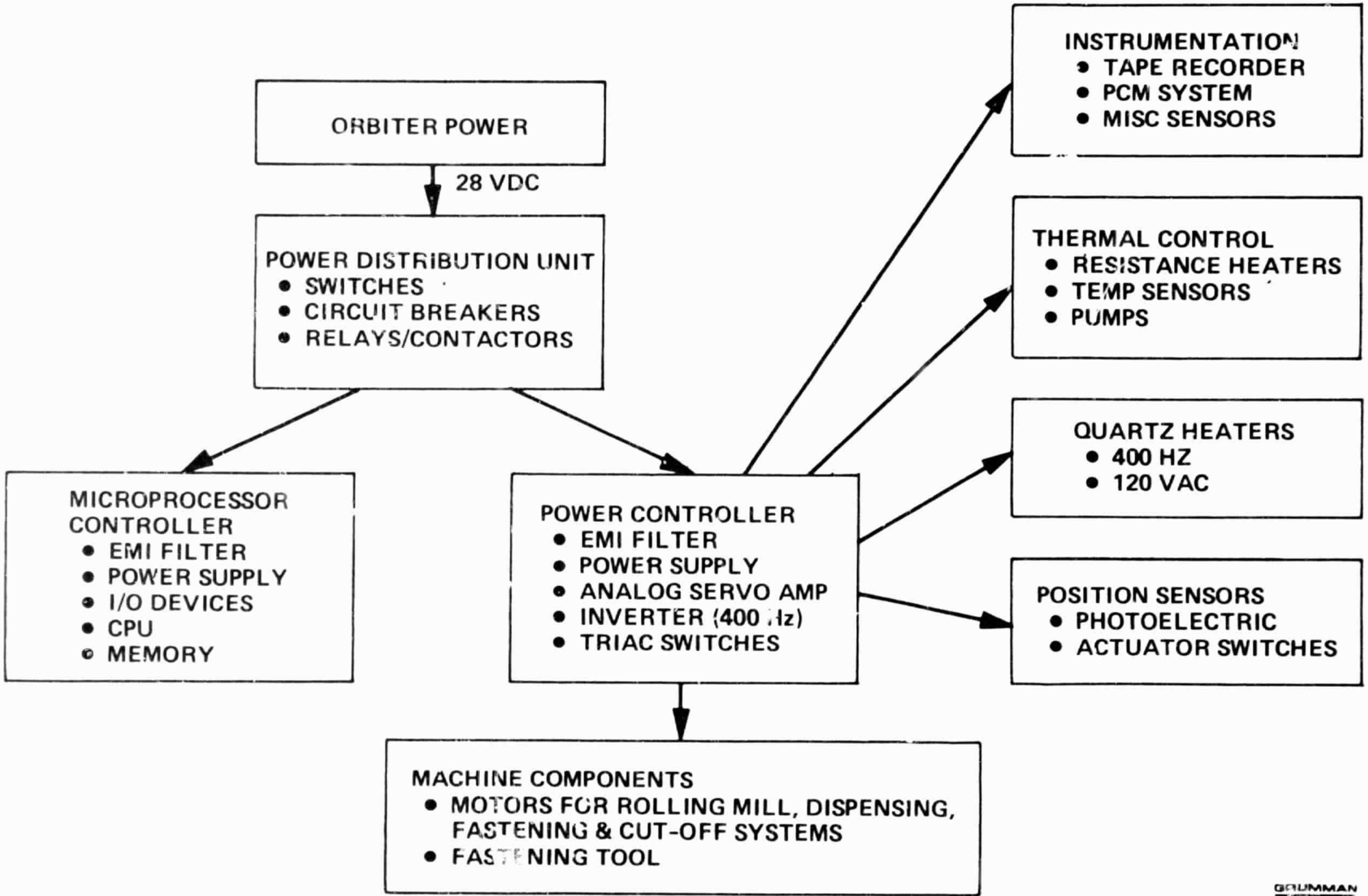
GRUMMAN

1230-023B

CBCF FLIGHT EXPERIMENT POWER DISTRIBUTION

The diagram shows the flow of electrical power from one component to another as well as the major functions of the power utilizing components and subsystems.

CBCF FLIGHT EXPERIMENT POWER DISTRIBUTION



ORIGINAL PAGE IS OF POOR QUALITY

GRUMMAN

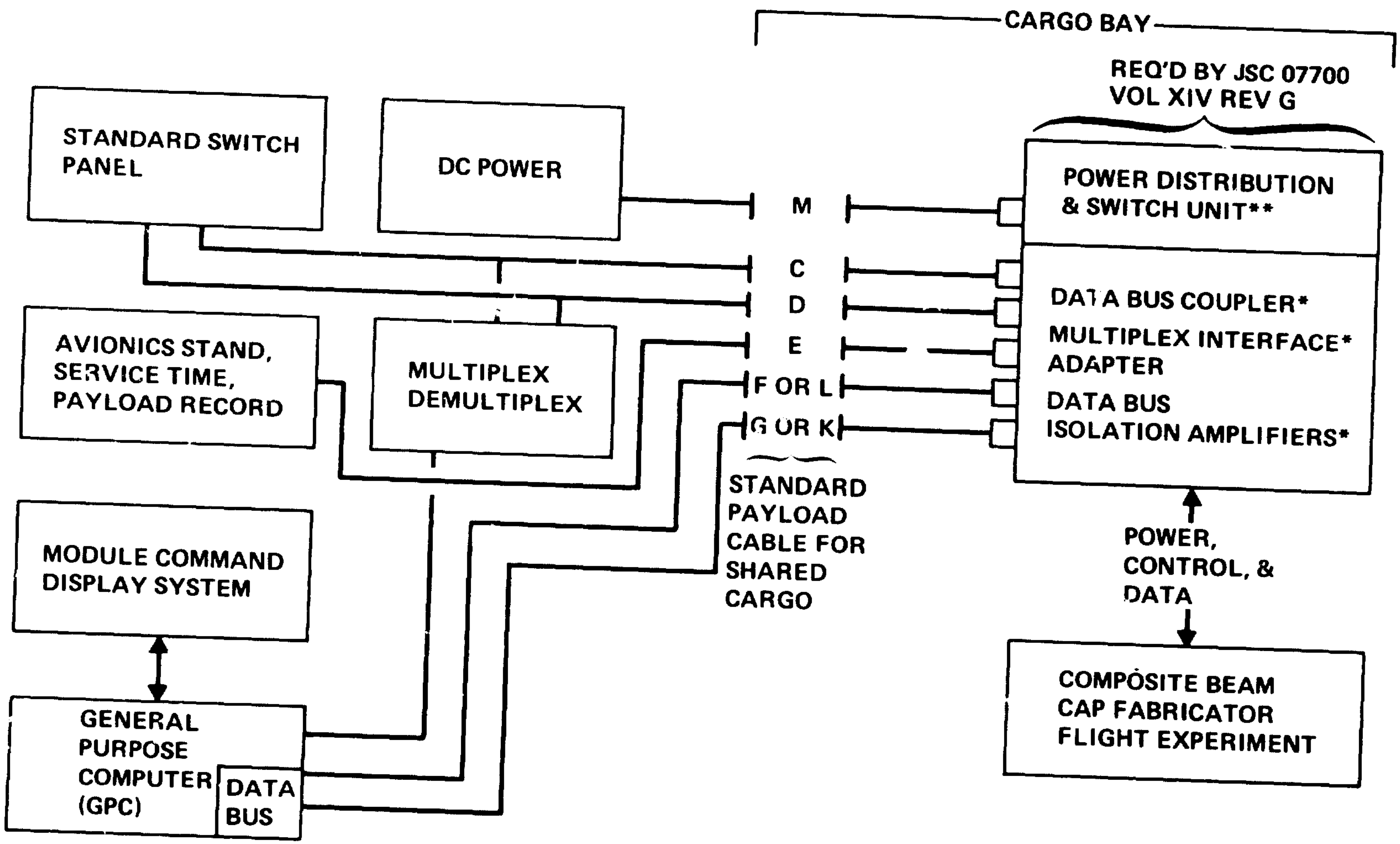
V82-0630-009P

POWER, CONTROL, DISPLAY AND DATA INTERFACES

This block diagram relates Orbiter supplied components used by the CBCF flight experiment to payload supplied components required when using the Orbiter's facilities. The Orbiter supplied components, most of which are in the cabin area, are shown on the left. Items on the right are located in the cargo bay and are supplied by the payload.

The 4 units in the upper right are required by the Payload Accomodations document, JSC 07700. The Power Distribution & Switch Unit is contained in the Grumman designed Power Controller. The remaining 3 components are needed to use the Orbiter's General Purpose Computer (GPC). The GPC selectively displays experiment data to the astronauts. Since the 3 interface units are required for all users of the GPC, some NASA centers have an inventory available for borrowing. To minimize the cost of this flight experiment, it has been assumed that these 3 units will be available for our use at no cost.

POWER, CONTROL, DISPLAY AND DATA INTERFACES



*NEEDED BY GPC FOR DATA DISPLAYS IN CABIN

**PART OF FLIGHT EXPERIMENT ELECTRONICS

GRUMMAN

1230-015B

CAP FABRICATION POWER PROFILE

The main sources of power consumption are the 8 quartz heating lamps (which are used to soften the cap material for roll forming) and the 2 inverters which convert Orbiter power (28 VDC) into 400 Hz 120 VAC. The inverters and quartz heaters will consume approximately 2500 watts while a cap is being roll formed – 2.1 min to produce the 1st 30 inches of cap. The remaining electronics and electrical losses are approximately 500 W while the heaters are drawing power.

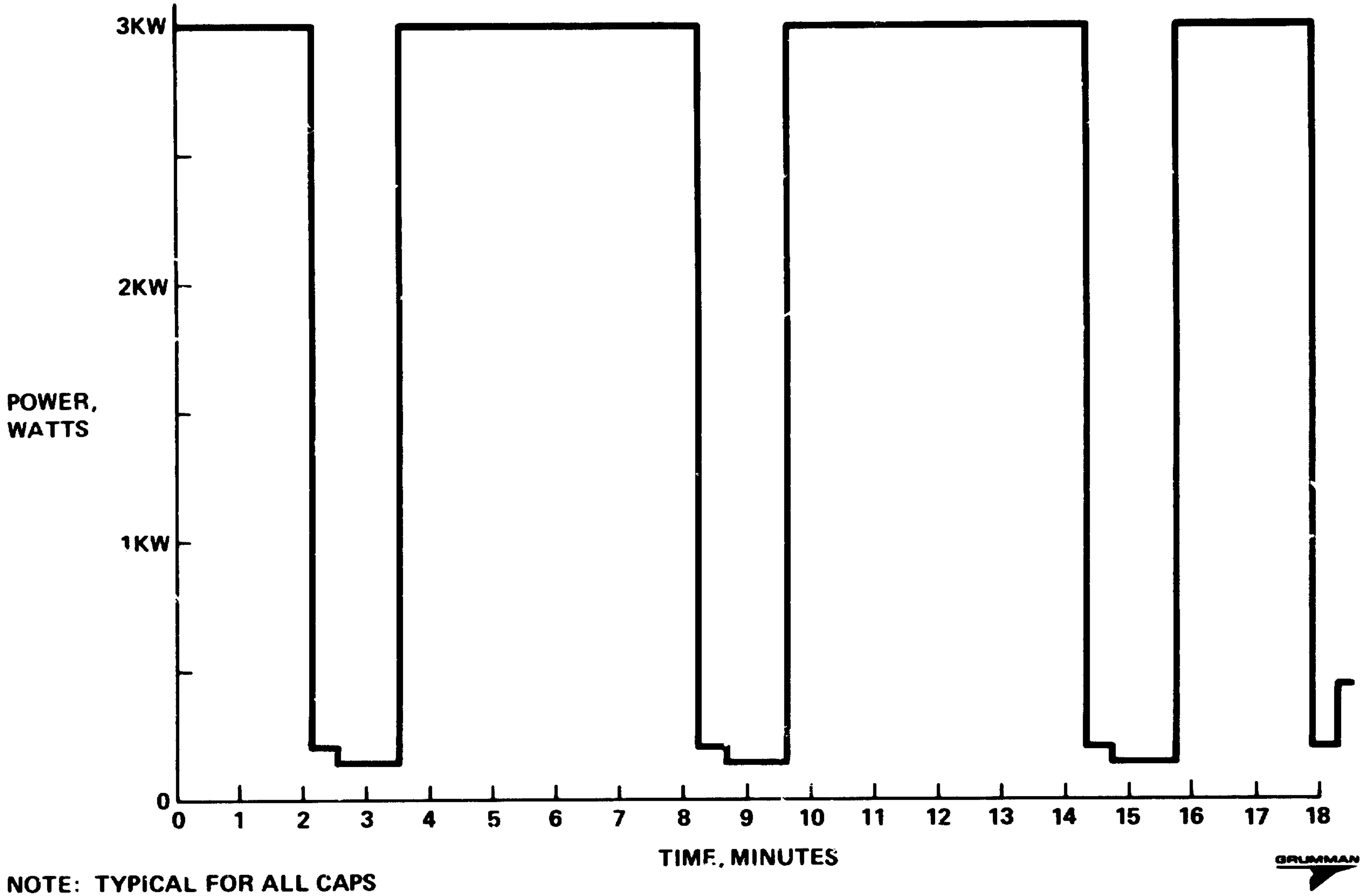
To accommodate fastening operations, a formed cap is backed up approximately 6 inches so that unformed material has enough time under the heating lamps to sufficiently soften when cap production resumes. During this phase, which lasts for ½ minute, system power demands are very low (~ 200 watts).

During the one minute interval a cap is stopped for fastening, average power demands are even lower (~ 150 watts). While the induction fastening tool is operating (20 seconds is assumed for an improved induction fastening tool), its power consumption is 100 watts. It has been assumed that power requirements to get the tool to and from the fastening position also equal 100 watts.

After the first fastening cycle, cap production resumes until an additional 66 in. of cap are formed. Then the cycles repeat as shown on the power profile.

CAP FABRICATION POWER PROFILE

• TOTAL ENERGY CONSUMED ~ 700 WATT HOURS/CAP



NOTE: TYPICAL FOR ALL CAPS

1230-016B

ORIGINAL PAGE IS
OF POOR QUALITY

INSTRUMENTATION LIST

Instrumentation is needed for the flight experiment for two distinct purposes. Since the experiment is fully automated, some instruments are needed for the on-going operation of the experiment. Others are needed to assure that the environment within the experiment (e.g., temperature) is satisfactory for the conduct of the experiment. The second major purpose of some instruments is to measure (directly or indirectly) the performance of an experiment subsystem while the experiment is in progress.

INSTRUMENTATION LIST

INSTRUMENT	LOCATION	QUANTITY	PURPOSE
THERMOCOUPLE	ROLLING MILL BEARINGS	5	MONITOR EFFECTIVENESS OF LUBRICATION
THERMOCOUPLE	ROLLING MILL MOTOR	1	MONITOR EFFECTIVENESS OF LUBRICATION
THERMOCOUPLE	ROLLING MILL GEAR BOX	1	MONITOR EFFECTIVENESS OF LUBRICATION
THERMOCOUPLE	CONTAINERS	10	MAINTAIN MACHINE TEMP AT 70°F
THERMOCOUPLE	MACHINERY	10	MAINTAIN MACHINE TEMP AT 70°F
OPTICAL PYROMETER	ROLLING MILL	4	SENSE CAP TEMP FOR HEATER CONTROL
OPTICAL PYROMETER	ROLLING MILL TRANSMISSION	2	MONITOR EFFECTIVENESS OF GEAR LUBRICATION
LINEAR POTENTIOMETER	ROLLING MILL	2	MEASURE POSITION OF 2 FEATURES ON A PARTIALLY FORMED CAP
PHOTOELECTRIC SYST.	ROLLING MILL	2	VERIFY PRESENCE OF CAP IN HEATER ZONE
PHOTOELECTRIC SYST.	GUILLOTINES	4	VERIFY GUILLOTINE MOTION
PHOTOELECTRIC SYST.	FASTENING REGION	2	VERIFY BRACE TRANSFER TO FASTENING REGION
PHOTOELECTRIC SYST.	FASTENING REGION	4	VERIFY FASTENING TOOL POSITION AGAINST BRACE
POSITION ENCODER	ROLLING MILL INPUT	1	MEASURE CAP PRODUCTION RATE & "BOUNCING" POWER TRANSMISSION
QUARTZ CRYSTAL MICROBALANCE	EXTERNAL SURFACES OF FLT EXPT	10	MEASURE ANY CONTAMINATION ADDED TO PAYLOAD BAY BY CBCF FLT EXPT

GRUMMAN

1230-028B

THERMAL DESIGN

REQUIREMENTS

A) MAINTAIN 70°F (± ~ 10°) DURING INOPERATIVE PERIODS

- TO ASSURE THAT CAP BRACE MATERIAL EXPERIENCES A THERMAL RESPONSE DURING FABRICATION THAT IS CLOSE TO GROUND EXPERIENCE

B) COOL MACHINE & ELECTRONIC EQUIPMENT DURING OPERATION

- QUARTZ LAMPS MUST BE ACTIVELY COOLED (~ 500 WATTS) TO PREVENT DESTRUCTION

THERMAL DESIGN (CONTD)

Where possible, flight experiment components are located within fully enclosed insulated boxes. Room temperature is maintained with a simple control system that uses resistance heaters and a pumped glycol cooling fluid which uses the Orbiter's heat exchanger. For the open (vented) containers which surround the fastening and roll forming systems, insulated solar baffles may be used internally to limit heat transfer through the vents.

Several alternatives to the selected pump cooling system were considered. The fluid pump system was judged to have the lowest total cost and lowest risk.

C-2

THERMAL DESIGN (CONTD)

SOLUTIONS

A) ENCLOSE MACHINERY & STORAGE SPOOL WITHIN INSULATED BOXES

- MULTILAYER INSULATED BLANKET
- PREVENT EXPOSURE TO DIRECT SUNLIGHT
- USE CONVENTIONAL RESISTANCE HEATERS & THERMOSTATIC CONTROL

B) FLUID COOLING LOOP COUPLED TO ORBITER HEAT EXCHANGER

- QUARTZ LAMPS ARE DESIGNED FOR FLUID COOLING
- TOTAL MACHINE POWER TO BE DISSIPATED ~ 2.5 KW
- COST OF SPACE QUALIFIED PUMPING SYSTEM ~ $200,000
- ALTERNATE SOLUTIONS CONSIDERED
  - HEAT PIPES INSTEAD OF PUMPED FLUID
    - VERY EXPENSIVE ENGINEERING BUT LOW HARDWARE COST
  - FLUID LOOP TO EXTERNAL RADIATOR
    - UNNECESSARY EXPENSE BUT MAKES EXPT INDEPENDENT OF ORBITER COOLING
  - USE EXPERIMENT STRUCTURE AS HEAT SINK
    - AVERAGE STRUCTURAL Δ T = 50° WHICH IS TOO HIGH FOR CONTINUOUS RUNNING
    - LOCAL HOT SPOTS OF 100°F INDICATED; DETAILED ANALYSIS REQUIRED

GRUMMAN

V82-0630-030P

CAP STORAGE FIXTURE

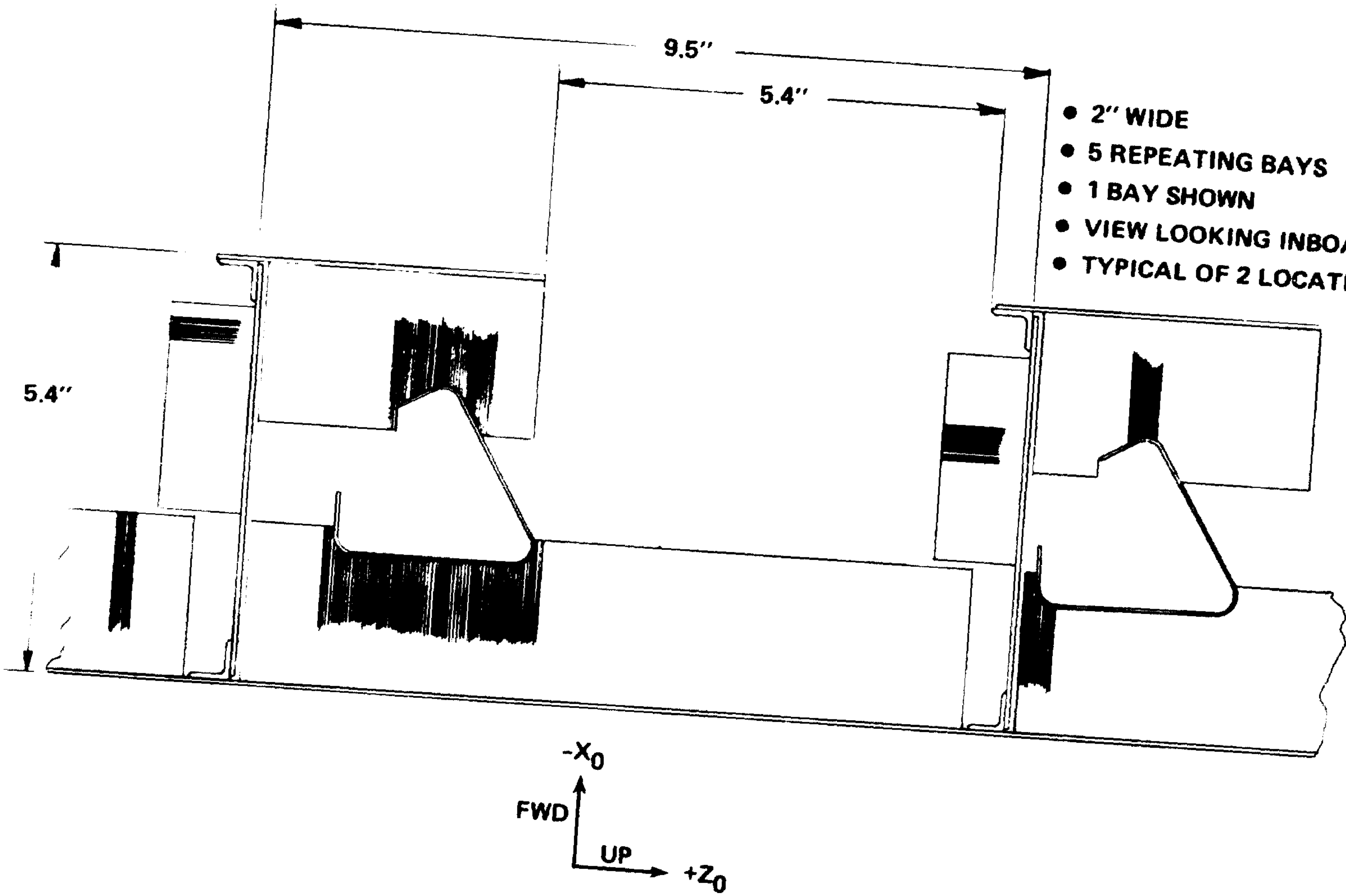
The cap storage fixture is used to retain the cap during orbital operations, reentry and landing. It is designed to be compatible with RMS use for inserting a cap.

The cap is retained by flexible fiber brushes which are attached to the walls of the fixture. The brushes were chosen as an inexpensive, self-equillibrating retention system that can cope with the relatively large position uncertainties introduced by the RMS. These uncertainties are on the order of ±2" according to RMS specifications. However, work at Grumman on an RMS simulator has indicated that ±1.5" is comfortable after an operator has practiced the activity several times. Consequently, the cap storage fixture provides a clearance of ±1½" at the entrance ($\pm Z_o$ directions) and, in the fore and aft directions ($\pm X_o$), ±1½" RMS misalignment is accomodated by fiber flexibility.

Two cap storage fixtures are used to retain a fabricated cap. A cap is placed in these fixtures by a $+ X_o$ (aft) motion of the RMS (which supports the cap at the middle, between the 2 fixtures) through the brush opening. RMS $+ X_o$ motion stops at a pre-established coordinate. Then $- Z_o$ RMS motion starts until another pre-established coordinate is reached. After vertical motion stops, the RMS unlocks the cap (there is an active lock on the tool the RMS uses to transport a cap) and moves in the forward ($- X_o$) direction. Any tendency of a cap to remain with the RMS is prevented by the forward face of the cap storage fixture as the RMS leaves the region. Fiber forces restore a cap to the positions shown on the facing page.

Although fiber forces are relatively weak, high landing loads on a cap are supported by the fixture structure which backs up the fibers. An unclosed opening is acceptable since there are no landing loads which combine forward and upward forces, or upward followed by forward forces, on a cap. Fiber forces will be adequate to restrain a cap against forces generated during orbital maneuvers.

CAP STORAGE FIXTURE



- 2" WIDE
- 5 REPEATING BAYS
- 1 BAY SHOWN
- VIEW LOOKING INBOARD
- TYPICAL OF 2 LOCATIONS

1230-010B

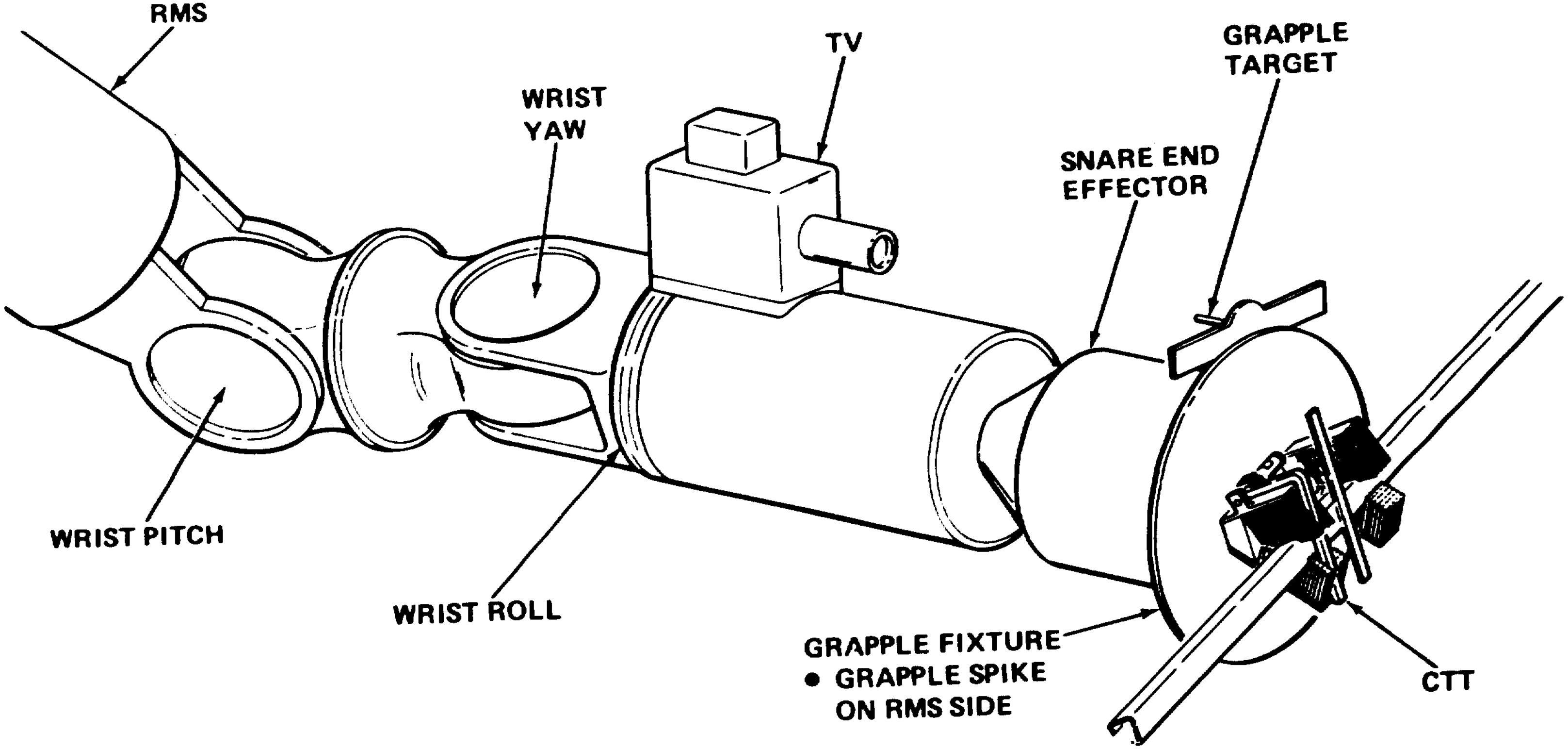
CAP TRANSPORT TOOL

If there is to be no EVA during the flight, this flight experiment requires a special tool which is attached to the RMS and is capable of engaging, restraining, transporting, and removing a cap from the flight experiment fabrication machinery – a Cap Transport Tool (CTT).

The RMS uses a rate controlled servo system. Without tactile feedback, it will develop all the forces needed to move itself in the instructed direction. This characteristic, combined with an inability to place the end of the RMS exactly where it is needed, implies the need for a CTT to be less stiff than a cap. The brush retention system shown on the facing page accomplishes this. It permits cap removal from the experiment without jamming a cap.

Since the RMS may be used for other experiments which share the payload bay, the RMS must be able to capture the CTT and remove it from its storage fixture. After experiment completion, it must return the CTT to its storage fixture and disengage it from the RMS. This engaging and disengaging is accomplished using the standard snare end effector on the RMS. To engage the CTT with a snare end effector, a standard grapple fitting may be used. A major problem with the arrangement shown on the facing page is that the best (and most reliable) source of visibility – the wrist mounted RMS TV – is blocked by the grapple target. Further, the main area of interest – the CTT/cap interface region – is outside this TV camera's field of view and the disc mounting the grapple system blocks RMS operator visibility from the aft flight deck.

RMS/CTT INTERFACE CONSIDERATIONS



ORIGINAL PAGE IS OF POOR QUALITY

- GRAPPLE TARGET BLOCKS VISABILITY WHILE USING CAP TRANSPORT TOOL TO
  - ACQUIRE CAP FROM FABRICATION AREA
  - PLACE CAP IN CAP STORAGE FIXTURE

1230-006B

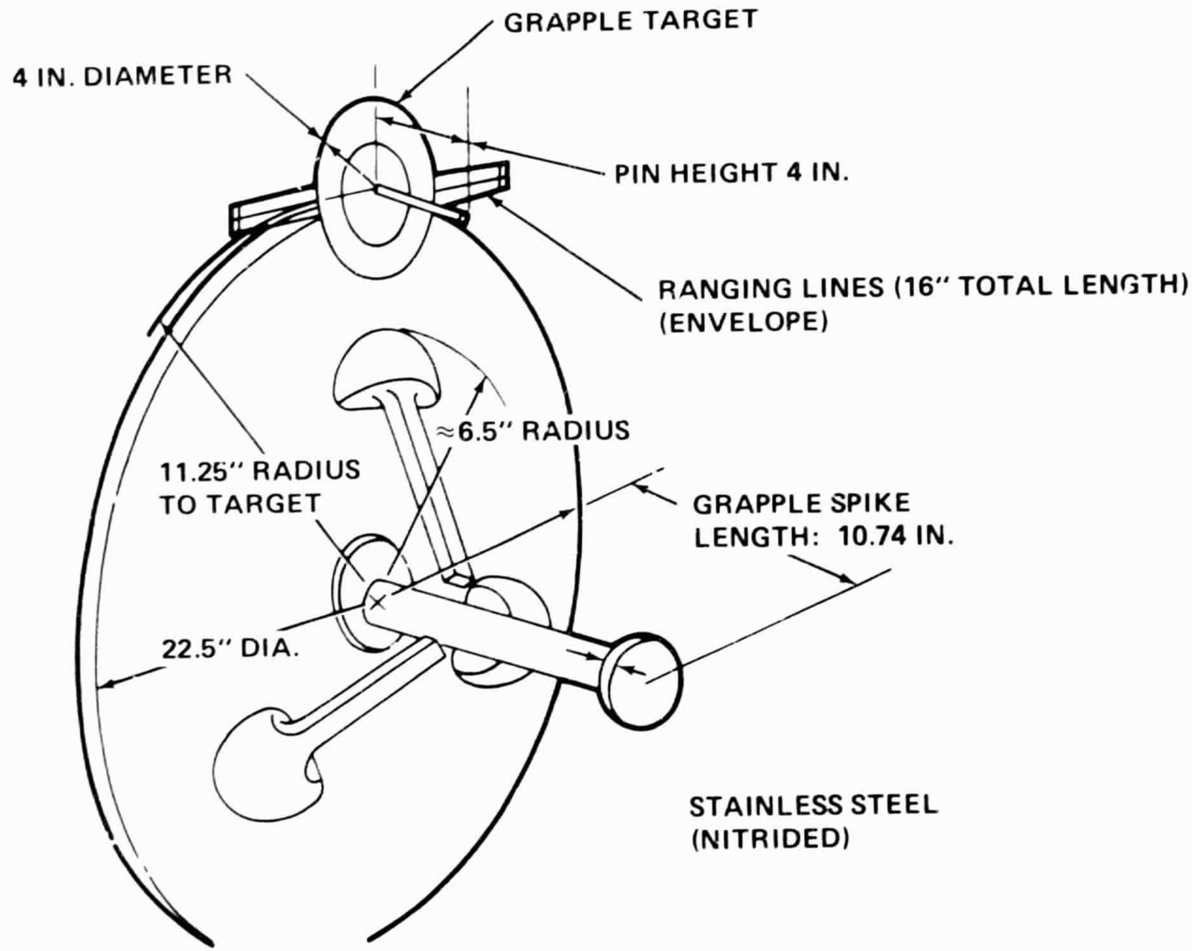
CTT/SNARE END EFFECTOR INTERFACE

The facing page chart shows some details of an interface structure used for the standard method of capturing an object with the snare on the end of an RMS. The plate, grapple target and grapple shown would be attached to an object requiring capture. By centering the FOV of the RMS wrist TV on the grapple target and using the white pin tip in the target for RMS translation information as the RMS moves closer to the grapple, the grapple spike is brought within the capture envelope of the snare end effector.

Since the only role of the grapple target is to provide optical guidance information for engaging the grapple spike, the grapple target can be removed and mounted on other structure. Also, the 22½" dia. disc can be reduced in diameter to 13 inches. The 13 inch diameter provides ample support for the grapple pin, its supporting struts and the electrical connector which is part of the grapple system. This reduced diameter grapple structure, together with a grapple target mounted elsewhere on the flight experiment structure, is used for the CTT design described in the following pages.

CTT/SNARE END EFFECTOR INTERFACE

- STANDARD GRAPPLE FIXTURE AND TARGET BUILT INTO CAP TRANSPORT TOOL (CTT) & CTT RETENTION FIXTURE



GRUMMAN

1230-023B

CAP TRANSPORT TOOL: DESIGN FEATURES

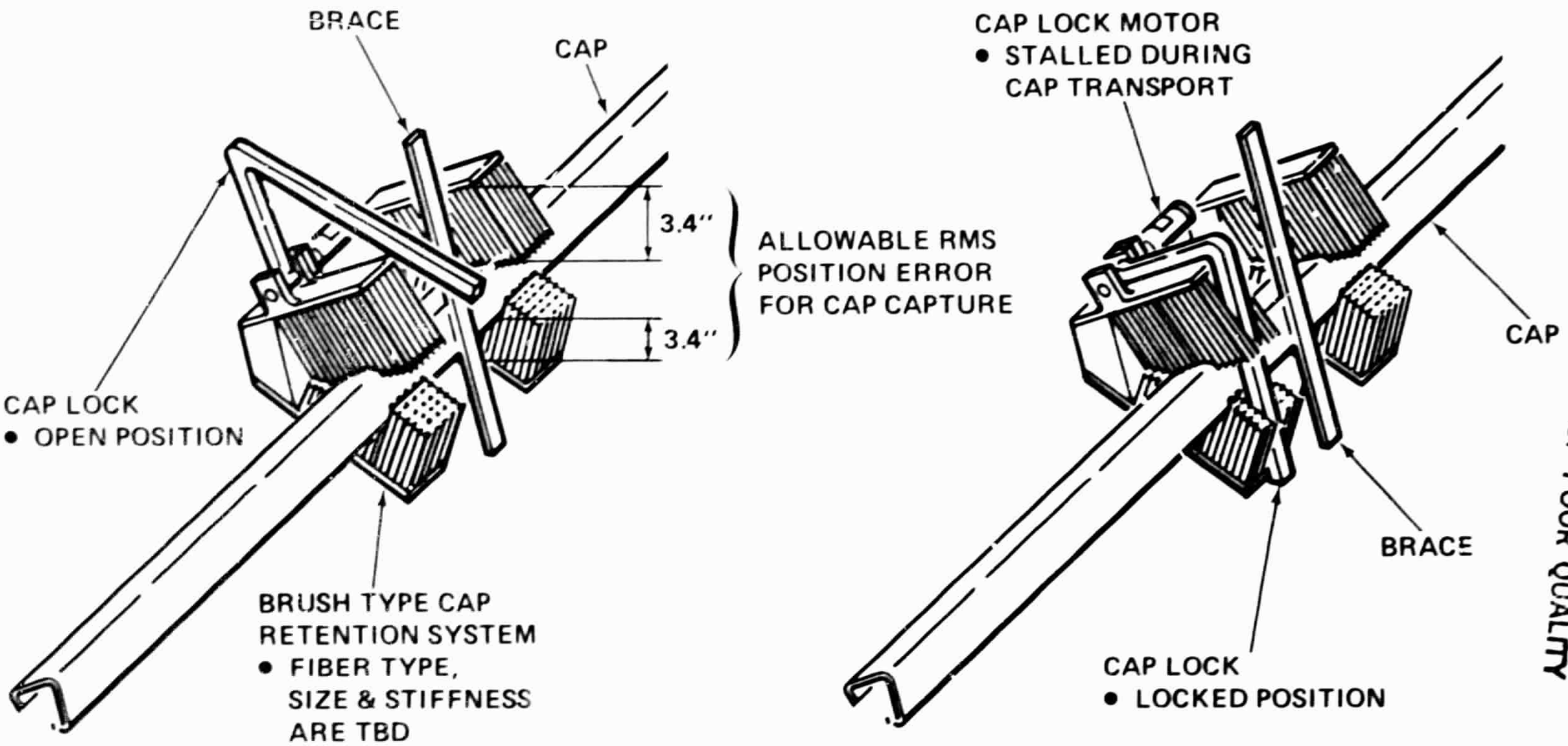
This chart shows some of the cap retention and control features of the recommended CTT design.

The CTT engages a cap at its middle. The 2 pairs of brushes and their supporting structures surround the central brace on a cap. The compliant brushes allow RMS position errors perpendicular to a cap in excess of ±3" in one direction. In the orthogonal direction, RMS position errors of nearly 2" are accomodated. Ample clearance exists for position errors along a cap's longitudinal centerline (Yo), and final values will be selected after brush characteristics have been determined.

To develop CTT forces on a cap parallel to the Yo axis (required to extricate a cap from the fabrication region), two mechanisms are available. Friction between cap and brushes is one source. Since both brush friction forces and the force required to extricate the cap are unknown at this time, this remains a potentially useful technique. Another source, capable of much higher forces, is to push on the brace with the CTT structure which supports the brushes. This has the disadvantage of moving the cap slightly off center with respect to the RMS.

A cap lock has been incorporated to positively trap the brace inside the CTT. This will prevent brace escape should some proceedural error cause a cap to strike a rigid object while in transport. The cap lock is a simple hinged bar which is driven against the structure which supports a brush. The lock is held in this possition during cap transport by stalling the cap lock motor.

CAP TRANSPORT TOOL: DESIGN FEATURES



- CAP LOCK REQUIREMENT: PREVENT BRACE SEPARATION FROM CTT IF RMS OPERATOR INADVERTENTLY ALLOWS BRACE TO HIT A FIXED OBJECT WHILE RMS IS MOVING BRACE TO A NEW LOCATION

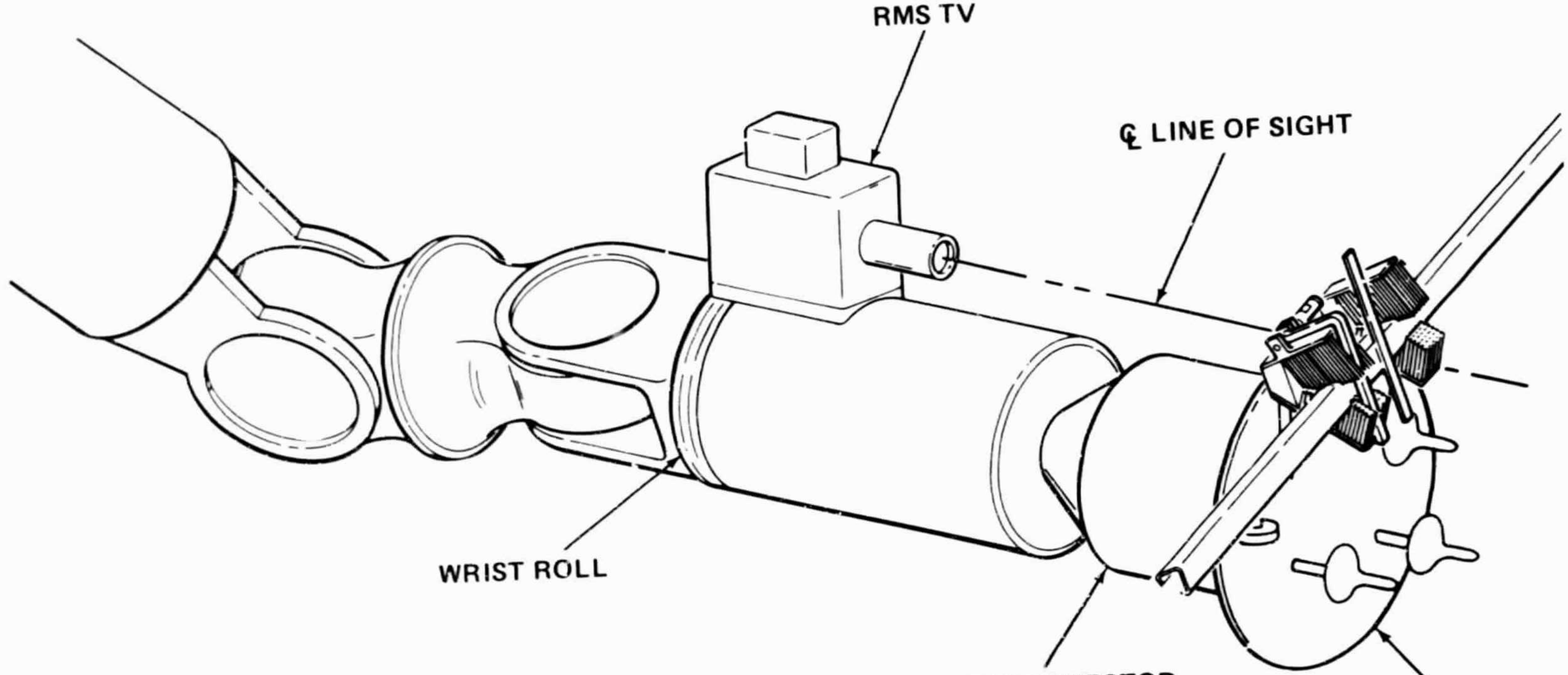
GRUMMAN

1230-001B

CTT ATTACHED TO RMS

This chart shows an improved CTT/RMS interface. The grapple fitting (which is buried within the snare on the RMS side of the plate) is mounted on a reduced diameter plate which does not contain a grapple target. The opposite side of the plate contains 3 CTT storage pins. These are used to guide and lock the CTT into its storage facility. The brush and cap retention region of the CTT have been moved up so that the center of the wrist TV's line of sight is aimed at the open space between the two pairs of brushes. This allows observation of the grapple target (when returning the CTT for storage) after all caps have been stowed. It also allows direct observation of a cap while securing it with the CTT.

CTT ATTACHED TO RMS



- FOR CAP AQUISITION, RMS OPERATOR AIMS CENTER OF TV FOV AT INTERSECTION OF CAP & BRACE
- FOR CTT STORAGE, OPERATOR AIMS FOV CENTER AT GRAPPLE TARGET ON EXPERIMENT STRUCTURE

GRUMMAN

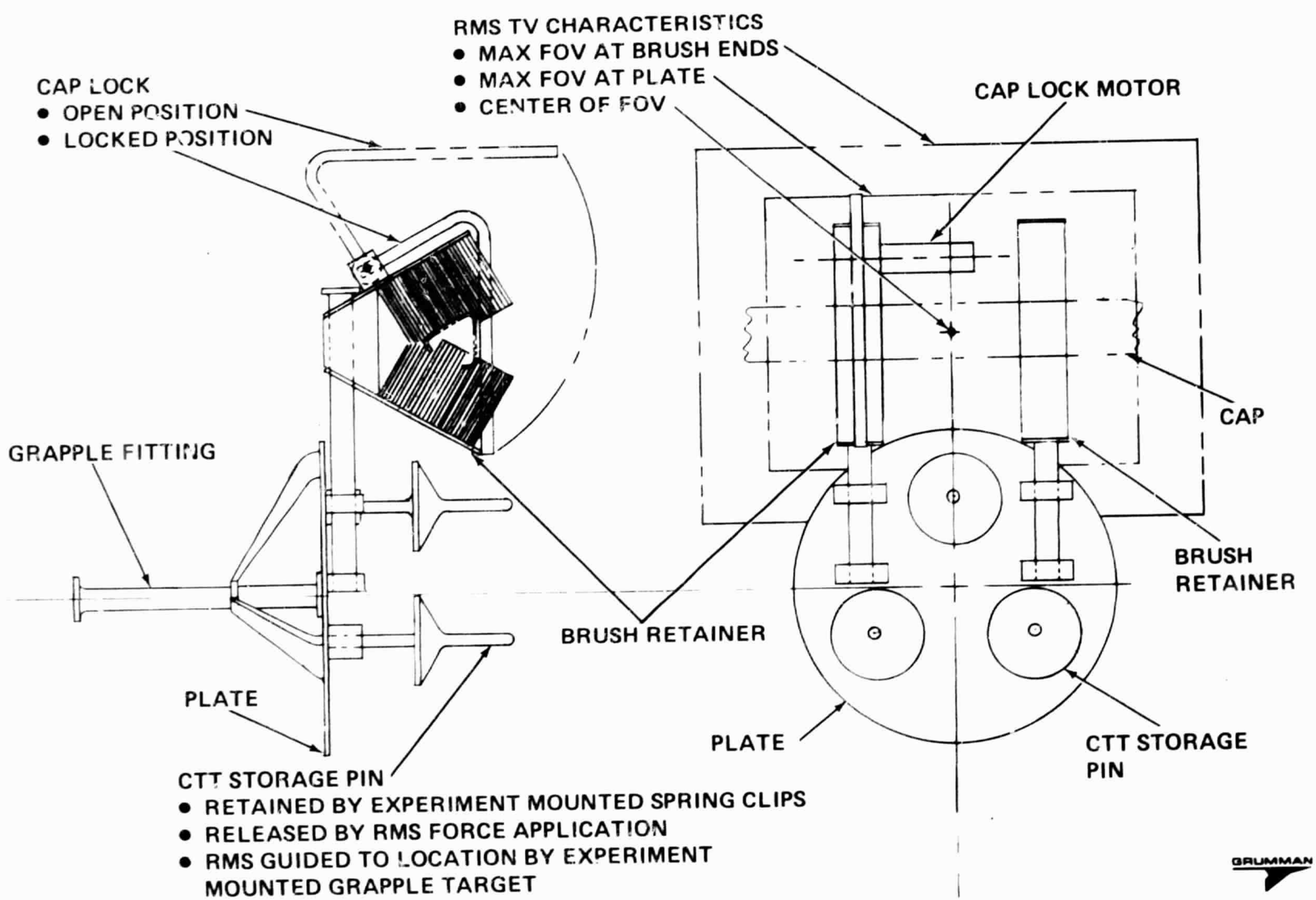
1230-008B

CAP TRANSPORT TOOL GENERAL ARRANGEMENT

This drawing shows two views of the recommended Cap Transport Tool.

In the right view, the TV field of view (FOV) has been centered at the intersection of a cap and the middle brace. Most of the camera's FOV (about 3/4 at the plane of the plate) is not obscured by the CTT. As the plane of observation is moved away from the camera, the visable portion of the FOV gets somewhat larger (4/5 at the ends of the brush restraints). The open, visable portions of the FOV can be used to sight on optical aids which can be attached to the experiment structure near the cap storage fixture. These optical aids can be used to accurately position the caps within their storage fixtures.

CAP TRANSPORT TOOL GENERAL ARRANGEMENT



GRUMMAN

1230-007B

CONSIDERATIONS ON EXPERIMENT LOCATION

A number of factors affect where in the payload bay this flight experiment can/should be located. Some of these are shown on the facing page. Of these, the first 2 items and the last item are discussed in detail later in this report.

Visability needs of both other payloads and this flight experiment are best established at a later phase of the CBCF Flight Experiment program than during this definition study. However, certain preliminary remarks are possible now. If this flight experiment is located in the aft section of the payload bay on a flight with deployable payloads (e.g., satellites), then no visability problems occur. Similarly, if this flight experiment is located in the most forward section of the bay, no visability problems occur for the CBCF. For other payloads whose visability is blocked by the CBCF, minimal viewing limitations could be obtained by reconfiguring this experiment. However, as is evident from the following pages, the forward experiment location precludes RMS use for cap stowage.

CONSIDERATIONS ON EXPERIMENT LOCATION

- RMS MOBILITY & REACH LIMITATIONS
- EMERGING CAP/ORBITER CLEARANCE
- VISABILITY OF CBCF FLIGHT EXPERIMENT
  - TASKS REQUIRING VISABILITY ARE:
    - CAP REMOVAL FROM EXPT AFTER CUTTING
    - CAP PLACEMENT IN CAP STORAGE FIXTURE
    - CTT ATTACHMENT & RELEASE FROM SNARE END EFFECTOR
  - PREFERRED → OBSERVATION FROM AFT FLIGHT DECK PLUS RMS WRIST TV
  - ACCEPTABLE → AFT BULKHEAD TV &/OR RMS WRIST TV
- OBSTRUCTING VISABILITY OF OTHER PAYLOADS
- CARGO BAY LENGTH/VOLUME LEFT BY OTHER PAYLOADS

GRUMMAN

1230-039B

RMS LIMITATIONS ON EXPERIMENT LOCATION

If this flight experiment is conducted without astronaut EVA, the RMS has three functions:

1) Remove cap from fabrication regime

2) Change cap attitude (i.e., rotate cap 180° about its centerline)

3) Place cap in its storage fixture.

Based on the configuration of the following pages, these 3 functions require definite levels of dexterity from the RMS. These dexterity levels were explored on a 1/24th scale payload bay model at Grumman. The RMS model contains all the degrees of freedom (DOF) and all the limitations on these DOF that are possessed by the RMS.

The first function can be handled by the RMS for all payload bay locations of the flight experiment function 2 cannot be performed in the last 8 feet of the payload bay. In this region, the RMS isn't long enough to permit a 90° pitch rotation of the snare end effector (ending with the snare vertical) while a cap is in the cap rotation clamps (see pages 119 and 125).

The thrid function has two limiting regions at the forward end of the payload bay. Within the first 20 feet of the payload bay, rectilinear vertical motion on the centerline of the bay is impossible since the end of the RMS is restricted to movement only along the surface of a sphere whose center is near the RMS shoulder at the left longeron. This prevents placing a cap into its storage fixture. In the next 5 ft of the payload bay, the snare end effector cannot be maintained in a horizontal (i.e., parallel to Xo) attitude while it moves below the RMS shoulder. This results in a change of cap attitude as it enters a cap storage fixture: the brace is no longer parallel to the Zo axis. Since some of this brace misalignment is tolerable, some of this 5 ft region is useful for the flight experiment.

These constraints imply that the flight experiment can only use 30 ft of the payload bay as potential attachment sites if astronaut EVA is not utilized. 75% of this room is available in the aft payload bay.

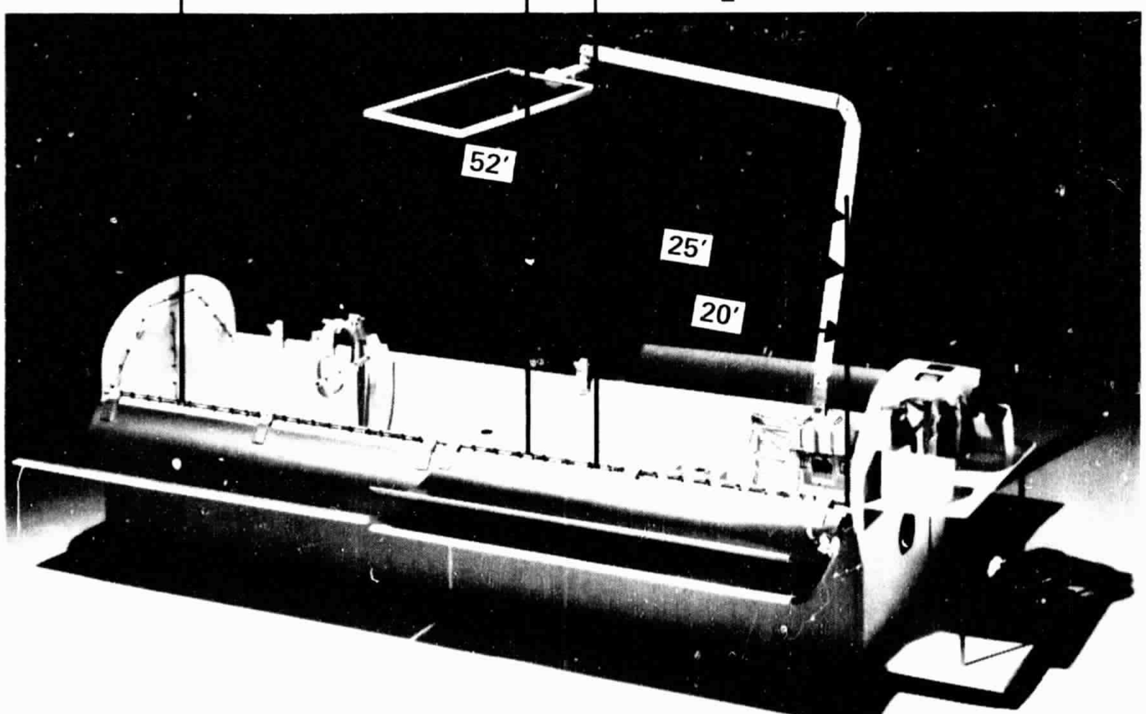
RMS LIMITATIONS ON EXPERIMENT LOCATION

- EVALUATION ON 1/24TH SCALE MODEL
  - CONTAINS ALL DOF & MOTION LIMITS OF RMS
- LIMITS APPLY TO RMS USE OF CAP ROTATION CLAMPS & PLACEMENT OF CAP IN CAP STORAGE FIXTURE
- 50% OF PAYLOAD BAY AVAILABLE TO RMS OPERATIONS

LIMIT OF 90° PITCH ROTATION OF SNARE

SNARE END EFFECTOR FORCED OFF HORIZONTAL (AFT END DOWN)

RMS UNABLE TO MOVE VERTICALLY ALONG, ℄ FROM TOP OF BAY TO 5′ ABOVE BOTTOM



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

GRUMMAN

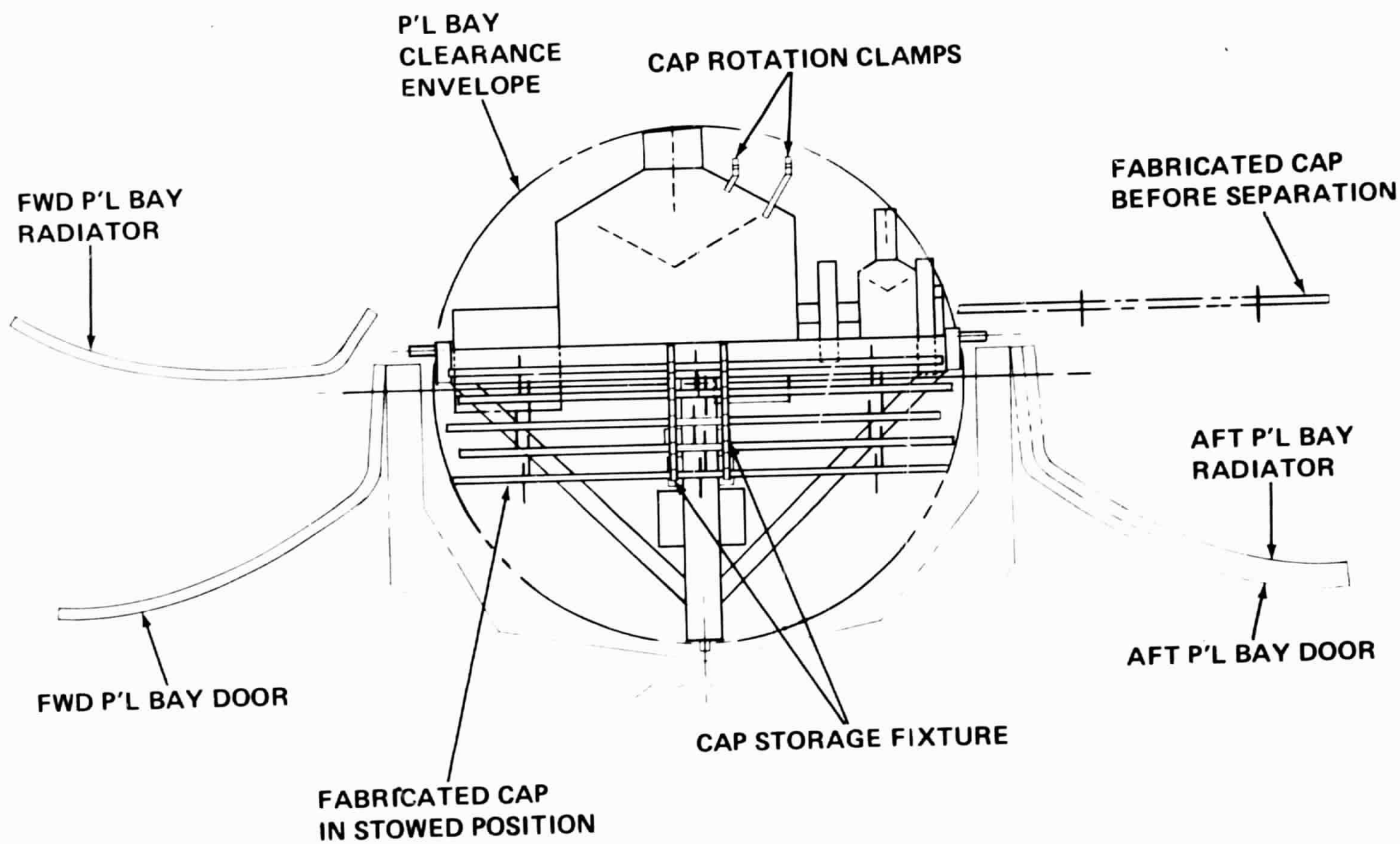
1230-027B

AFT PAYLOAD BAY CONFIGURATION

The principal difference between the aft and forward payload bay regions is the location of the Orbiter's radiators. The low radiator location in the aft bay permits the CBCF Flight Experiment's fabrication axis to be parallel to the Orbiter's Yo axis.

The drawing on the facing page shows the position of a cap after fabrication has been completed. The RMS has to grab the cap at the middle brace (the most inboard brace is still within the machine), perform a +Yo motion after cap cutoff to extricate the cap, then move the cap to the Cap Rotation Clamps where the RMS performs 2 successive 90° rotations to change the brace position from the forward to the aft side of the cap. The RMS must then transport and insert the cap into its storage fixture at the lower, forward side of th experiment.

AFT PAYLOAD BAY CONFIGURATION



VIEW LOOKING AFT AT PAYLOAD BAY

GRUMMAN

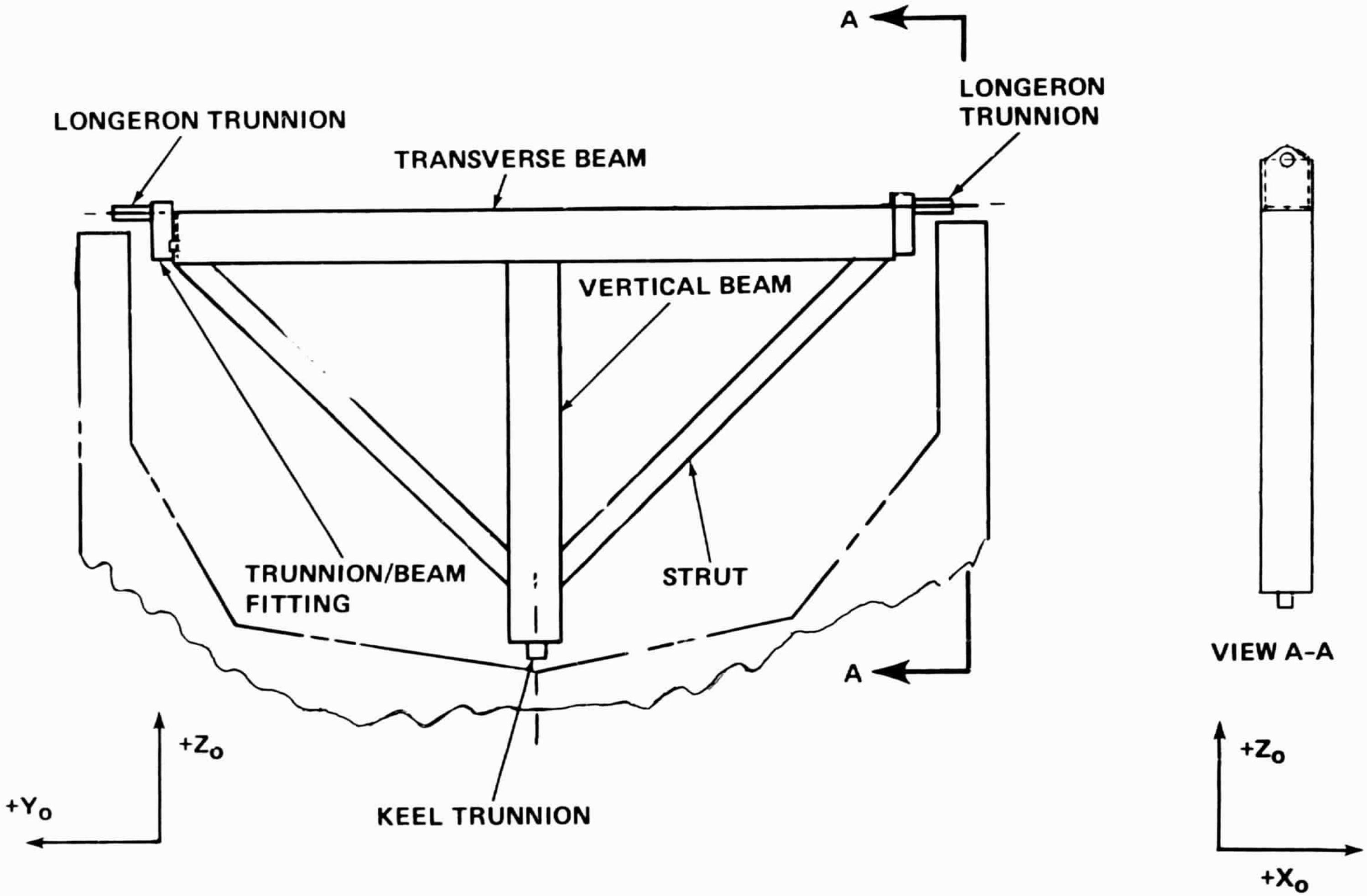
1230-003B

STRUCTURAL ARRANGEMENT OF AFT CONFIGURATION

The flight experiment uses a 3 point support system: a left and right longeron trunnion and a keel trunion. The longeron fittings react ±Xo & ±Zo while the primary loads into the keel fitting are ±Yo. Some ±Xo loads will be delivered to the keel fitting as it reacts to pitching moments on the experiment. These ±Xo loads are limited to small values at the keel. This should not be a problem since pitching loads can be minimized by configuration changes which move the experiment center of gravity (CG) in a Zo direction. On the Strawman design (page 39), the experiment CG was on the line joining the longeron trunions (Zo = 414).

The structure is made up of two beams. Most experiment systems are attached to the Transverse Beam, which is parallel to the fabrication axis. A Vertical Beam is cantilevered off the Transverse Beam. This Vertical Beam is supported by two struts which carry a part of the ±Yo load to the Keel Trunion.

STRUCTURAL ARRANGEMENT OF AFT CONFIGURATION



- LONGERON TRUNNION LOADS = $\pm X_O$ & $\pm Z_O$
- KEEL TRUNNION LOADS = $\pm Y_O$ & SMALL $\pm X_O$ FOR PITCH MOMENTS

1230-004B

AFT PAYLOAD BAY CONFIGURATION (CONT)

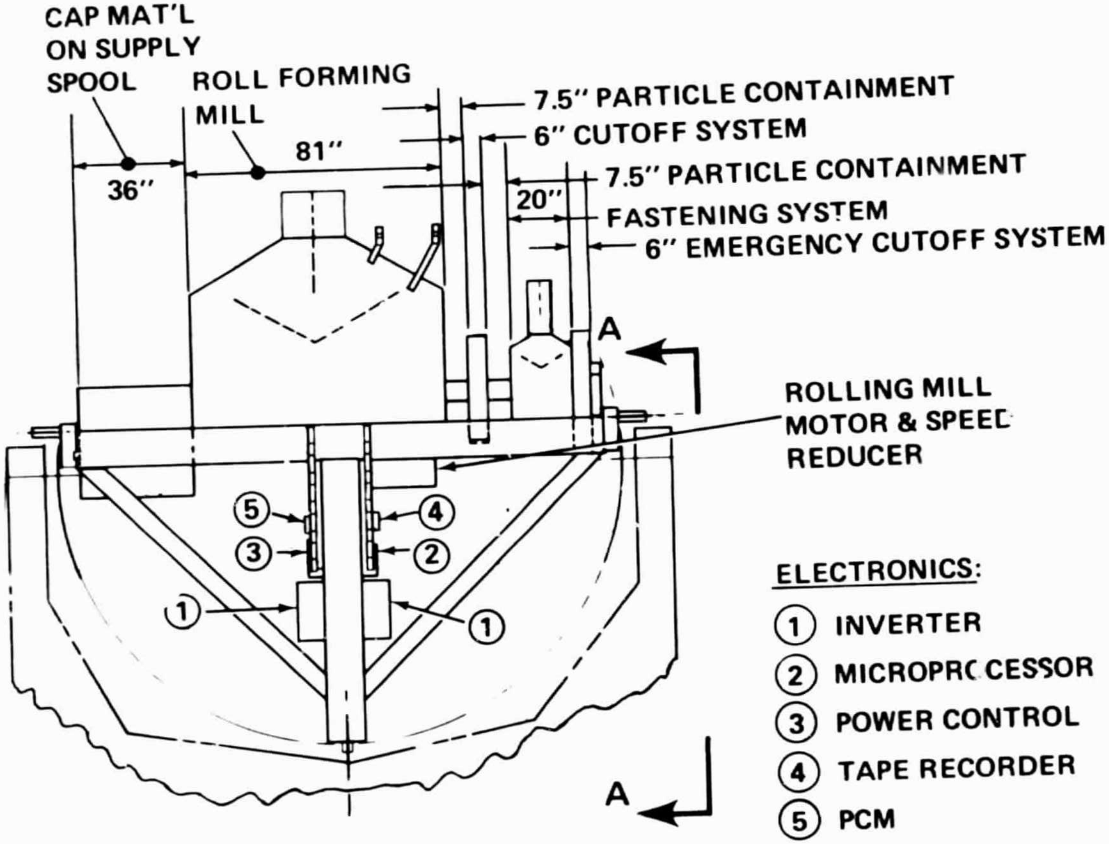
This chart amplifies some details of the Aft Payload Bay Configuration.

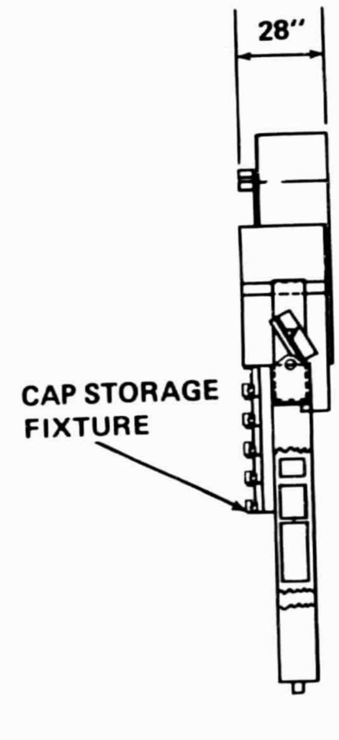
Approximately 3 feet have been allocated for a spool diameter on which unformed cap material is stored. Although a 2 foot diameter spool was specified for the ground demonstrator CBCF, a larger diameter was selected for the flight experiment to provide a margin of safety against viscoelastic behavior. While viscoelastic effects have been observed in polysulfone and polyethersulfone, the magnitude of the behavior is unknown. It is also unknown whether viscoelastic strains prior to roll forming will make a significant difference to the roll formed cap.

One of the major differences between this configuration and "Strawman" is the addition of an Emergency Cutoff System. This system, with it's own wires to a seperate power harness, satisfies a JSC 07700 requirement for payload operations which violate the payload door envelope and threaten the possibility of preventing payload door closure: " the hazard of preventing door closure must be controlled by independent primary and backup methods, and this combination must be two failure tolerant." Should the primary (inboard) Cutoff System fail to cut through a cap, or, should the RMS be unable to extricate a cap from the machinery, the Emergency Cutoff System would sever the cap at the most outboard machinery location. The RMS can then secure this cap and the experiment would terminate. The guillotine for the emergency system is identical to the guillotine for the primary system except that an additional stroke (~5") must be supplied to the emergency blade to permit clearance for a brace attached to an emerging cap.

Another change from "Strawman" is the relocation of the rolling mill drive motor and speed reducer below the Transverse Beam. This enabled the shorter length (28") launch envelope shown in View A-A.

AFT PAYLOAD BAY CONFIGURATION (CONT)





VIEW A—A

ORIGINAL PAGE IS
OF POOR QUALITY

GRUMMAN

1230-005B

UNRESTRICTED PAYLOAD BAY CONFIGURATION

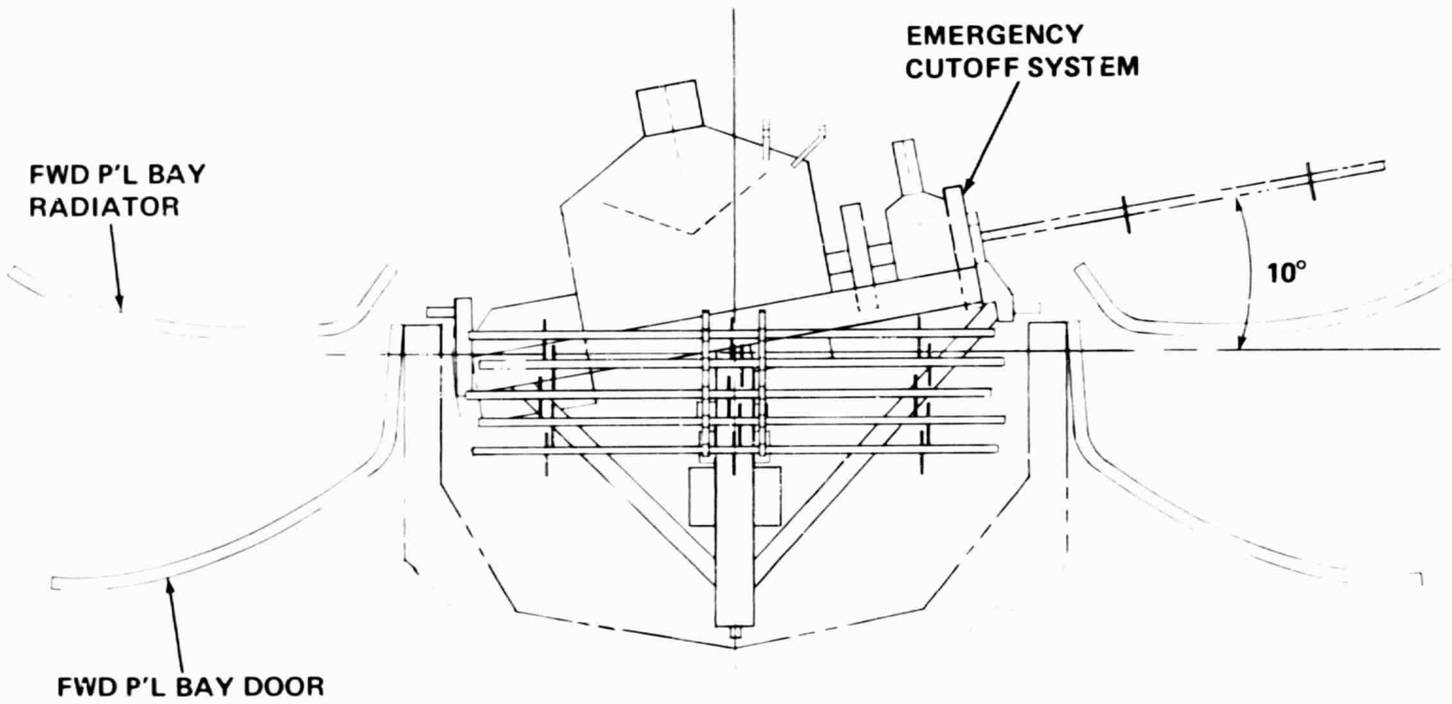
The Unrestricted Payload Bay Configuration was developed to permit the flight experiment to use the forward region of the payload bay as well as the aft region. Adequate clearance is obtained between an emerging Brace and the Forward Payload Bay Radiator when the cap fabrication axis is inclined 10° to the Yo axis (a "tilted" configuration).

The configuration on the facing page was obtained by tilting the Aft Payload Bay Configuration in a vertical plane. However, a simplification of orbital operations can be obtained by rotating the Transverse Beam, and everything above it, 180° about the Zo (vertical) axis. This would put the magazine on the forward side, where room now exists above the highest stored brace. The benefit to orbital operations would come from eliminating the need for cap rotation (and cap rotation clamps), since the braces on a fabricated cap would be produced on the aft cap surface – the requirement for insertion into the Cap Storage Fixture.

Should it be determined that use of the RMS is too restrictive on flight opportunities, a "tilted" configuration like the one described above is preferred for the flight experiment.

UNRESTRICTED PAYLOAD BAY CONFIGURATION

- LOCATED ANYWHERE IN PAYLOAD BAY
- SAME AS "AFT CONFIGURATION" EXCEPT
  - TRANSVERSE BEAM INCLINED 10° (LONGER STRUT)
  - MORE COMPLEX/COSTLY TRUNNION/BEAM FITTINGS
  - SMALLER SUPPLY SPOOL CONTAINER



- PREFERRED CONFIGURATION IF RMS USE ABANDONED IN FAVOR OF EVA
- PREFERRED CONFIGURATION IF FLIGHT DATE UNKNOWN
  - I.E., EXPERIMENT USES "FLIGHT OF OPPORTUNITY"

GRUMMAN

1230-002B

ROM WEIGHT ESTIMATE FOR CBCF FLT EXPT

These weight estimates are based upon accurate data on existing hardware and estimates of new designs formulated during this study.

ROM WEIGHT ESTIMATE FOR CBCF FLT EXPT

	WEIGHT (LB)
ROLLING MILL	(560)
4 STATIONS, MOTOR & GEARBOXES, AL BASEPLATE	350
QUARTZ LAMPS & SUPPORTS (8)	80
OPTICAL PYROMETERS & SUPPORTS (4)	10
PRESENCE SENSORS (PHOTOELECTRIC) (4)	5
STORAGE SPOOL, BRACKET & 100 FT OF GR/PES	70
ENTRY TABLE & ENCODER	35
STRAIGHTENING SECTION	10
CONTAMINATION CONTAINMENT	(230)
ROLLING MILL	110
STORAGE REEL	30
CUTOFF SYSTEM(2)	60
PARTICLE ENTRAPMENT	30
THERMAL CONTROL	45
CUTOFF SYSTEM (2)	380
MAGAZINE & STRIPS (20) & DISPENSING SYSTEM	10
FASTENING SYSTEM (INCLUDING SUPPORT STRUCTURE)	60
EARTH RETURN SUPPORTS (10) & CAP ROTATION CLAMPS	20
CAP TRANSPORT TOOL & SUPPORTS (OPTIONAL FOR NO EVA)	15
ELECTRICAL & ELECTRONICS	180
SUBTOTAL	1500 LB
PAYLOAD BAY SUPPORT STRUCTURE (20% MASS FRACTION FOR LOW COST STRUCTURE)	300
TOTAL WEIGHT	1800

GRUMMAN

1230-022B

CAP FABRICATION TIMELINE (TYPICAL FOR ALL CAPS)

The cap fabrication method, which was described on page 94, requires 18¾ minutes for manufacturing one 14 foot long cap.

CAP FABRICATION TIMELINE (TYPICAL FOR ALL CAPS)

EVENT	POWER W	EVENT TIME MIN/SEC	ELAPSED TIME MIN/SEC
1 BEGIN 1ST EXPERIMENT FWD FOR 30"	3000	2 : 8.6	2 : 8.6
2 REVERSE FOR 6"	200	25.7	2 : 34.3
3 CROSS MEMBER BOND TIME	150	1 : 00	3 : 34.3
4 FWD FOR 66"	3000	4 : 42.9	8 : 17.2
5 REVERSE FOR 6"	200	25.7	8 : 42.9
6 CROSS MEMBER BOND TIME	150	1 : 00	9 : 42.9
7 FWD FOR 66"	3000	4 : 42.9	14 : 25.8
8 REVERSE FOR 6"	200	25.7	14 : 51.5
9 CROSS MEMBER BOND TIME	150	1 : 00	15 : 51.5
10 FWD FOR 30"	3000	2 : 8.6	18 : 00.1
11 REVERSE FOR 6"	200	25.7	18 : 25.8
12 GUILLOTINE CUT	450	20.0	18 : 45.8

GRUMMAN

1230-017B

MISSION TIMELINE

The mission timeline assumes that the experiment operates continuously from the start of fabrication of the first cap to completion of the fifth cap. To do this, other payloads which share the bay must not be users of significant power (i.e., less than 100 watts) during the CBCF Flight Experiment if the CBCF Flight Experiment draws its electrical power from a Standard Mixed Cargo Harness (SMCH). If this mission timeline is desired, but the other payloads must consume some significant power, a SMCH can not be used. Instead, additional cabeling is required to draw power from the primary payload bus at Station 645.

As the first cap is nearing completion, two seperate activities take place simultaneously. The fabrication process continues in an automatic mode untill cap completion. Meanwhile, the RMS operator is preparing the RMS for use. After cap cutoff (under operator command), as the RMS operator stows the cap for earth return, the fabrication machinery is automatically producing a new cap.

The total time an operator spends for RMS control is 1 hour (58 minutes in the table). The total time the fabrication machinery operates is 1½ hours (1 hour, 36 minutes, 59 seconds in the table). The total elapsed time for the entire flight experiment is 2 hours (1 hour, 50 minutes, 59 seconds in the table).

ORIGINAL PAGE IS
OF POOR QUALITY

MISSION TIMELINE

- ASSUMES THAT POWER IS OBTAINED FROM STA 645 PRIMARY P/L BUS OR OTHER PAYLOADS OFF – 3 KW CONTINUOUS ALLOWED

EVENTS				EVENT TIME				MISSION ELAPSED TIME					
NO.	FABRICATION OF CAP/BRACE	NO.	STOWING FABRICATED CAP	MIN FAB	MIN STO	SEC FAB	SEC STO	HR FAB	HR STO	MIN FAB	MIN STO	SEC FAB	SEC STO
1	BEGIN 1st EXPERIMENT FAB CAP FWD FOR 30"			2		8.6				2		8.6	
2	REVERSE CAP MOTION FOR 6"			0		25.7				2		34.3	
3	BRACE DISPENSE & BOND			1		0				3		34.3	
4	FAB CAP FWD FOR 66"			4		42.9				8		17.2	
5	REVERSE CAP MOTION FOR 6"			0		25.7				8		42.9	
6	BRACE DISPENSE & BOND			1		0				9		42.9	
7	FAB CAP FWD FOR 66"	1	UNCRADLE RMS	4	2	42.9	0			14	2	25.8	0
8	REVERSE CAP MOTION FOR 6"	2	GRAPPLE CTT	0	2	25.7	0			14	4	51.5	0
9	BRACE DISPENSE & BOND			1		0				15	4	51.5	0
10	FAB CAP FWD FOR 30"			2		8.6				18	4	0.1	0

GRUMMAN

1230-029B

MISSION TIMELINE (CONT)

EVENTS				EVENT TIME				MISSION ELAPSED TIME					
NO.	FABRICATION OF CAP/BRACE	NO.	STOWING FABRICATED CAP	MIN FAB	MIN STO	SEC FAB	SEC STO	HR FAB	HR STO	MIN FAB	MIN STO	SEC FAB	SEC STO
11	REVERSE CAP MOTION FOR 6"			0	0	25.7	0			18	4	25.8	0
		3	GRASP CAP WITH CTT	0	3	0	0			21	7	25.8	0
12	GUILLOTINE CAP			0		20.0				21	7	45.8	0
		4	REMOVE CAP FROM EXPT	0	0	0	10			21	7	55.8	10
13	FABRICATE 2nd CAP	5	MANEUVER 1st CAP TO ROTATION FIXTURE AND THEN STORAGE	18	6	45.8	50			40	14	41.6	0
14	FABRICATE 3rd CAP	6	GRASP AND STOW 2nd CAP	18	10	45.8	0			59	24	27.4	0
15	FABRICATE 4th CAP	7	GRASP AND STOW 3rd CAP	18	10	45.8	0	1		18	34	13.2	
16	FABRICATE 5th CAP	8	GRASP AND STOW 4th CAP	18	10	45.8	0	1		36	44	59	
		9	GRASP AND STOW 5th CAP		10		0	1		36	54	59	
		10	STOW CTT		2		0	1		36	56	59	
		11	CRADLE RMS		2		0	1		36	58	59	
												TOTAL TIME = 1: 50: 59	

GRUMMAN

PAGE 132 INTENTIONALLY BLANK

1230-030B

HAZARD ANALYSIS

A hazard analysis was conducted so that concerns about crew and Orbiter safety would be introduced early in the design process. For this study, it was influential in establishing a need for an Emergency Cutoff System and a cap lock on the Cap Transport Tool.

With the flight experiment configured as described herein, none of the hazards listed on the facing page pose a serious threat to crew, Orbiter, other payloads or the flight experiment itself.

HAZARD ANALYSIS

HAZARD CONDITION	POSSIBLE CAUSES	HAZARD EFFECT	CORRECTIVE ACTION	ASSESSMENT
1. FAILURE TO REMOVE CAP FROM CBCF	• PRIMARY GUILLOTINE FAILURE • JAMMED END CAP	• WILL PREVENT THE PAYLOAD BAY DOORS FROM CLOSING	• USE EMERGENCY GUILLOTINE • PERFORM AN EVA AND MANUALLY CUT CAP, FREE OR UNJAM	• HIGHLY UNLIKELY TO HAPPEN. MANY SUCCESSFUL TESTS CONDUCTED IN 1G ENVIRONMENT
2. RMS CTT LOSES MANUFACTURED CAP WHILE MANEUVERING IT INTO STOWAGE	• CAP HITS OTHER PAY-LOADS OR EXPERI-MENTS	• LOOSE CAP WILL INTERFER WITH OTHER EXPERIMENTS AND MAY PREVENT DOORS FROM CLOSING	• MANUEVER ORBITER AWAY FROM FREE FLOATING CAP	• POSSITIVE CAP RETENTION SHOULD PRECLUDE OCCURANCE. SIMULATION OF FLIGHT OPERATION SHOULD MINIMIZE OPERATOR ERROR
3. COOLANT LEAK	• HOSE CONNECTION COMES LOOSE • HOLE IN LINE	• CONTAMINATE PAY-LOAD BAY, JEOPARD-IZE VISIBILITY OR OTHER EXPERIMENTS	• SHUT PUMP DOWN, CLOSE ALL VALVES, MANEUVER ORBITER AWAY FROM COOLANT WHICH HAS ESCAPED	• HIGHLY UNLIKELY OCCURANCE. EXPERIMENT WILL BE TERMINATED.
4. CAP STOWAGE RETENTION SYST RELEASES CAP	• OPERATOR DISLODGES PREVIOUSLY STOWED CAP DURING STOWING OF NEXT CAP	• SAME AS ITEM 2	• TRY TO CAPTURE CAP AND REATTEMPT TO STOW • SAME AS ITEM 2 • EVA RETRIEVAL AND STOWAGE	• SAME AS ITEM 2

GRUMMAN

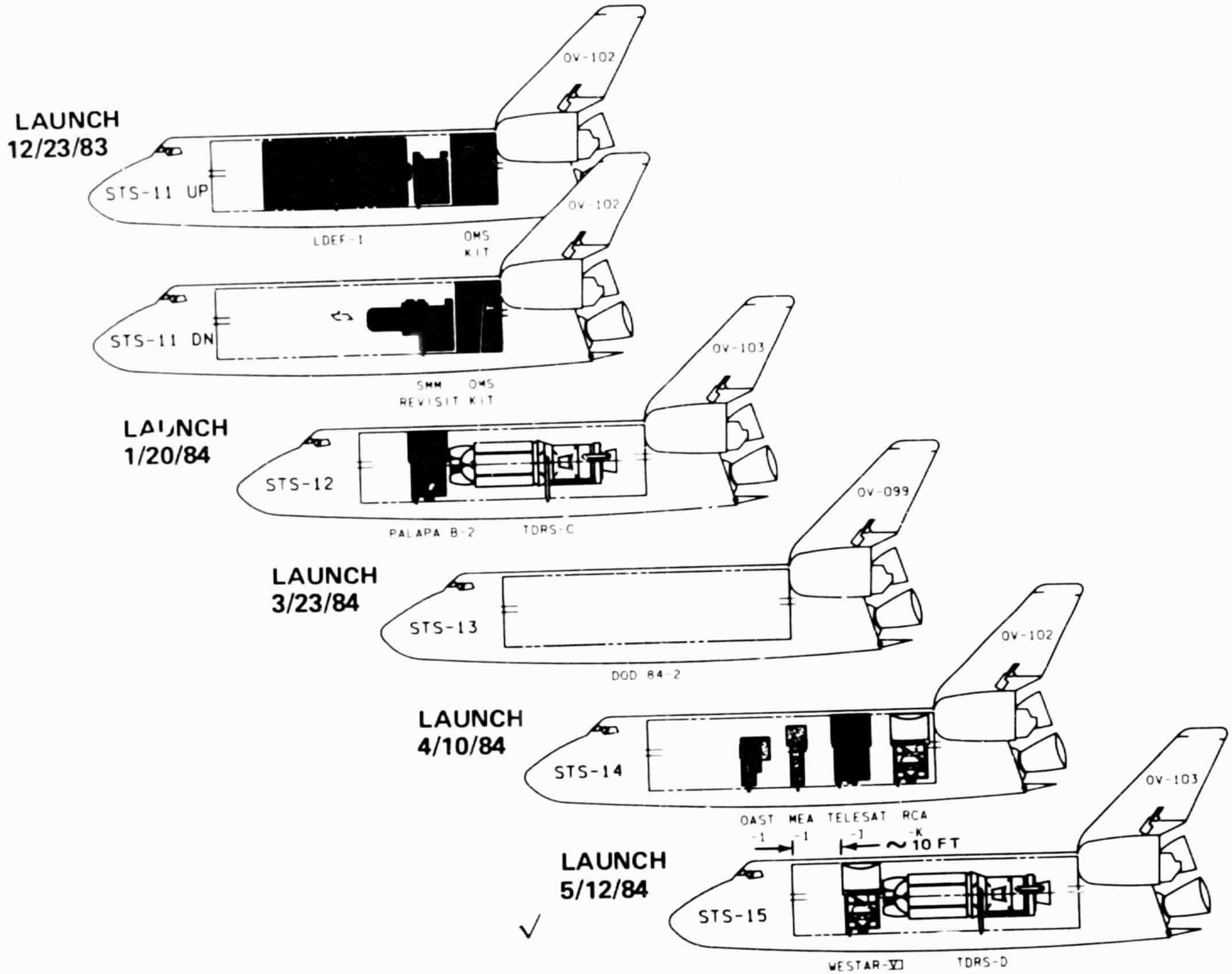
1230-031B

POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT

The next 5 drawings depict Space Transportation System (STS) payload launch allocations as of February 1982. The time period of May 1984 through September 1985 was selected for examination. This time period starts with the earliest possible CBCF flight opportunity, assuming immediate funding of this program.

The drawings define volume and, in some instances, weight restrictions for additional payloads. For example, STS-15 (bottom of facing page) has 10 feet of open payload bay at the forward end and 5.5 feet of open payload bat at the aft end. Consequently, a $\checkmark$ has been placed alongside it indicating that this flight is available for the CBCF Flight Experiment.

POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT



GRUMMAN

1230-034B

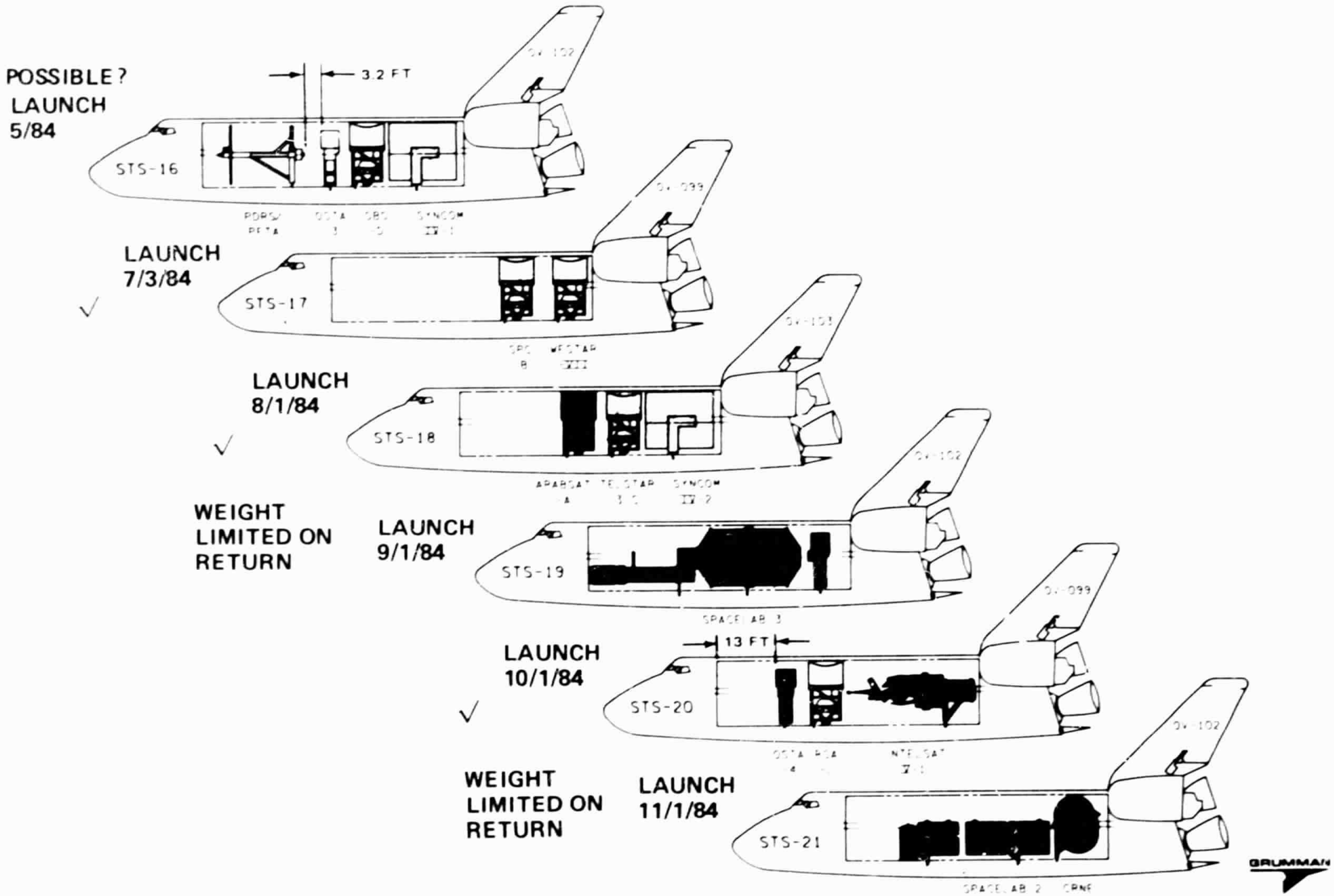
POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT (CONTD)

STS-16 is considered a possible launch because there appears to be 10 inches more space between PDRS/PFTA & OSTA-3 than is occupied by this flight experiment. However, the location of available keel & longeron fittings plus the dynamic envelopes of all three payloads are unknown at this time. Since it is not obvious now that the CBCF Flight Experiment can fit into this space, STS-16 is rated "possible".

STS-17, STS-18 & STS-20 have ample capacity for additional volume and weight. They are ranked "definite" (√) launch opportunities.

STS-19 & STS-21 cannot accept additional payload weight for the return to earth portion of their flight.

POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT (CONTD)



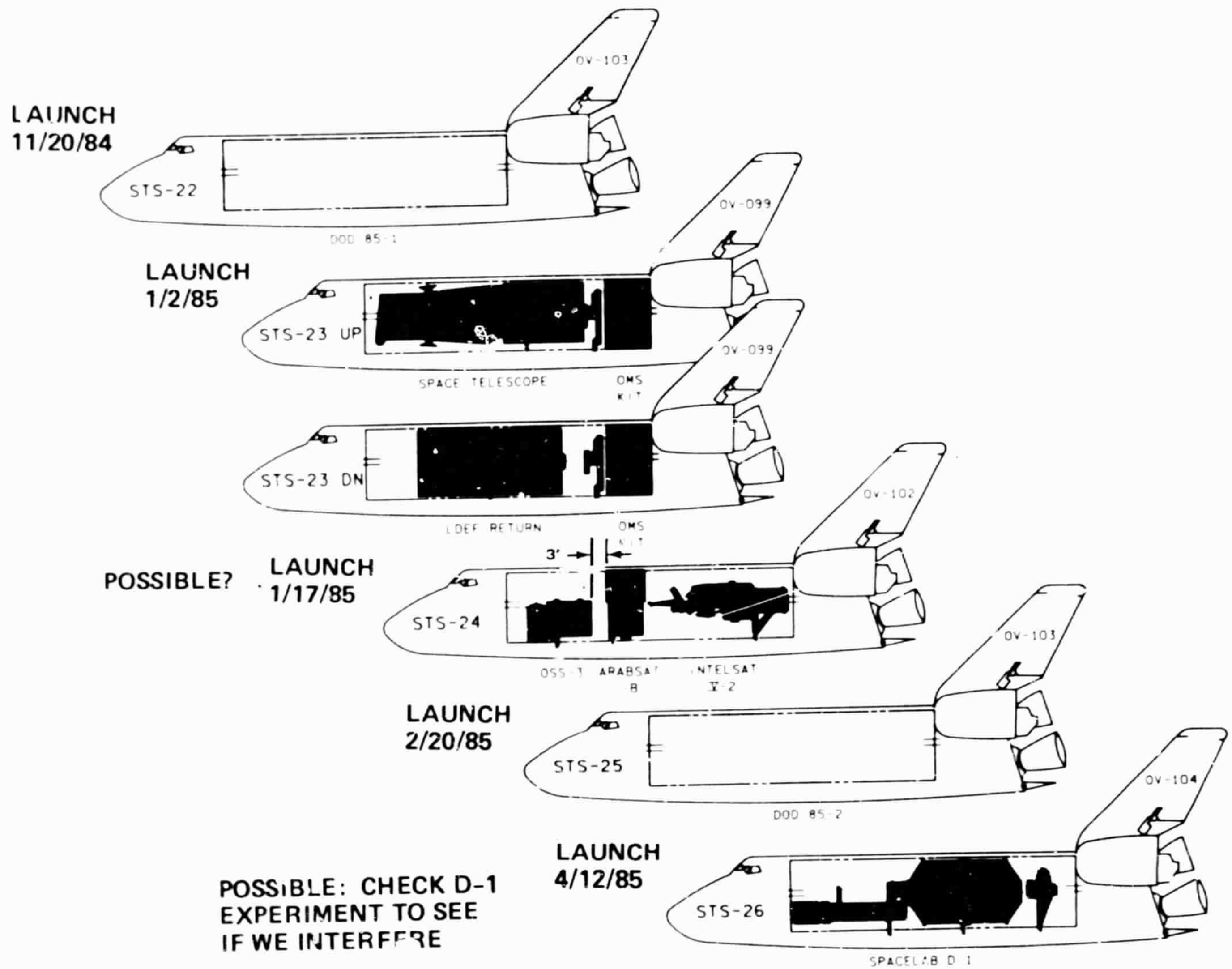
V82-0630-013P

POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT (CONTD)

Since STS-22 & STS-25 are DOD flight with unknown payloads, they were not considered in this examination.

STS-26 is considered "possible" because 3.8 feet of space are unoccupied at the aft end and, there exists the option of redesigning the ±Yo load carrying structure to surround the Spacelab Tunnel in order to pick up a keel fitting. However, it is currently unknown whether the presence or behavior of the CBCF Flight Experiment will distrub the Spacelab D-1 experiment.

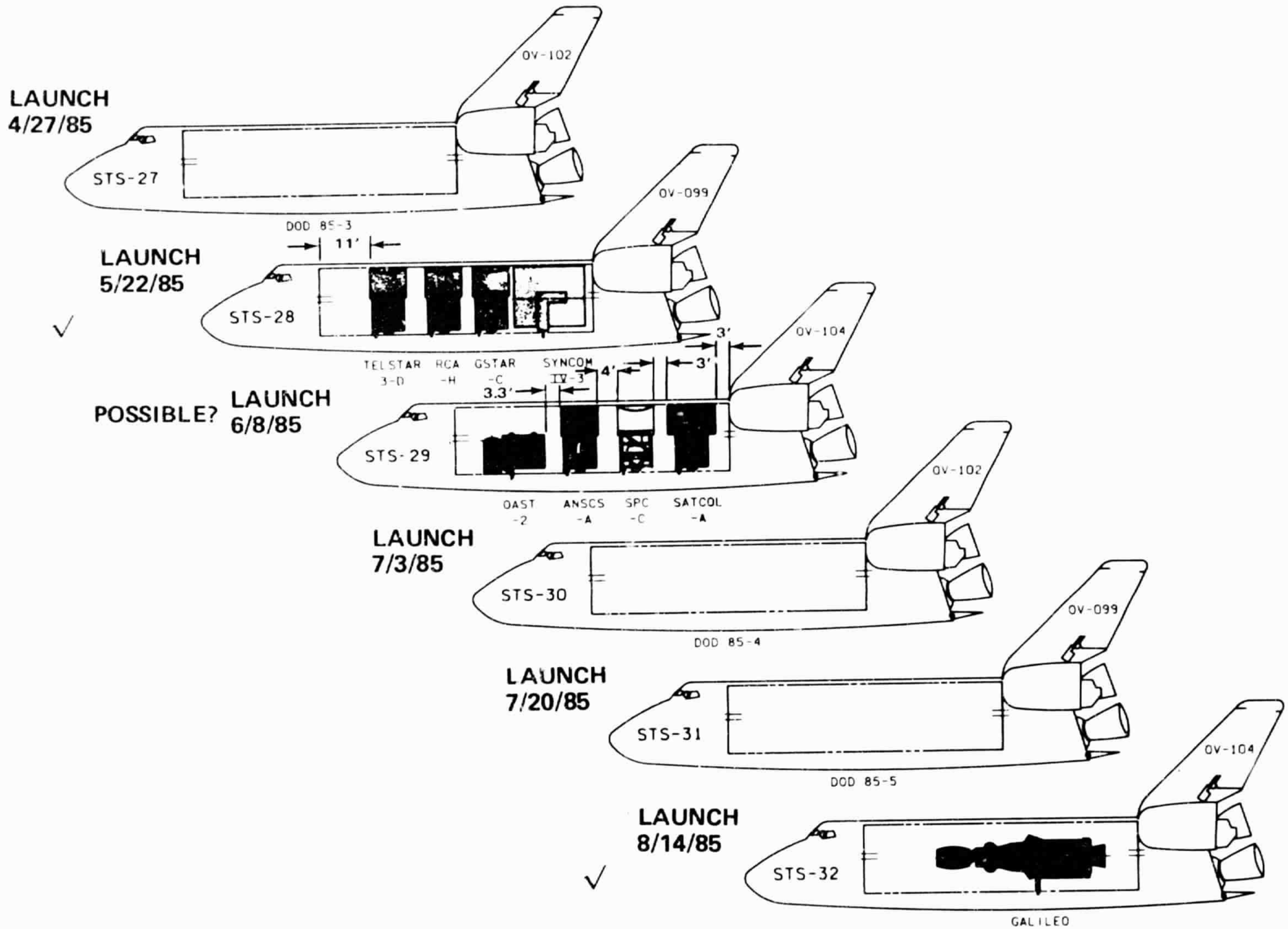
POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT (CONTD)



GRUMMAN

V82-0630-014P

POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT (CONTD)



ORIGINAL PAGE IS OF POOR QUALITY

GRUMMAN

V82-0630-015P

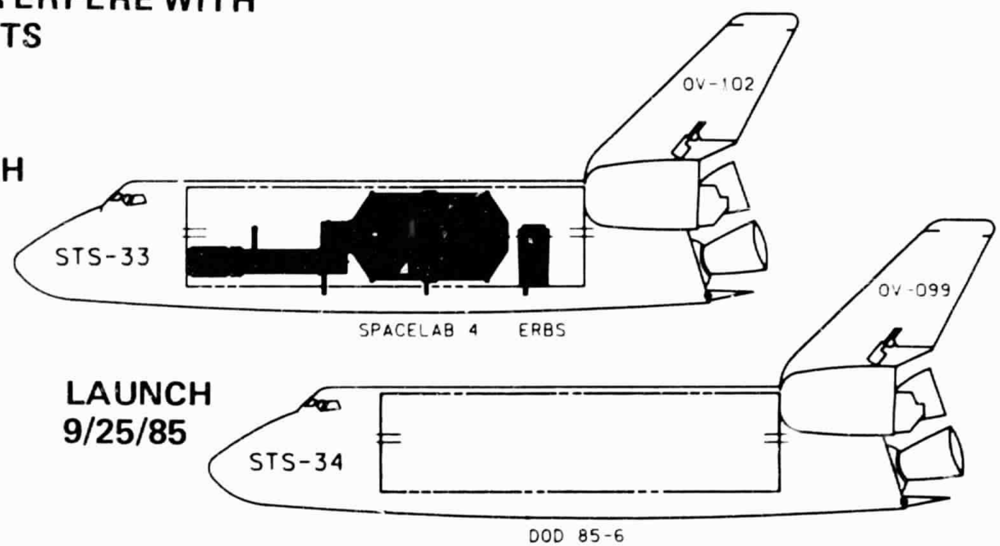
PAGE 142 INTENTIONALLY BLANK

POTENTIAL FLIGHTS FOR CBCF FLT EXPERIMENT (CONTD)

POSSIBLE: CHECK TO SEE IF
WE WILL INTERFERE WITH
EXPERIMENTS

LAUNCH
9/1/85

LAUNCH
9/25/85



V82-0630-016P

SOME CONSTRAINTS ON FLIGHT OPPORTUNITY

The concept of a "suitcase flight experiment" implies a smallness of size that allows launch on one of many different flights. The table on the facing page identifies the limitations on the number of available flight opportunities which are imposed by the constraints discussed within this report.

In the 1984-85 time period, NASA flight are scheduled at a rate of about 9 per year, or an average rate of 1 flight every 1½ months. This implies that a flight experiment configuration whose availability (the last column on the facing page) equals 50% would only have to wait (at most) 3 months from the time it was ready for launch untill it was able to be launched. This condition is met by constraint #1, and, approximately, by Constraint #3 on the facing page. Similarly, the configuration of Constraint #2, with a 1 out of 3 availability, might have to wait about 5 months for launch while the configuration of constraint #4 (availability of 1 out of 7) might have to wait 11 months for launch. None of these waiting periods seem excessive. However, if the number of suitcase experiments waiting for a flight exceeds 1, the configuration of Constraint #4 becomes unappealing.

SOME CONSTRAINTS ON FLIGHT OPPORTUNITY

ORIGINAL PAGE IS OF POOR QUALITY

- FLIGHT SCHEDULE EXAMINED: MAY 1984 → SEPT 1985
  – CONTAINED 14 NASA LAUNCHES (OUT OF 20 LAUNCHES)

CONSTRAINT	AVAILABLE FLIGHTS			AVAILABILITY: PORTION OF TOTAL FLTS EXAMINED
	DEFINITE	POSSIBLE	TOTAL	
1. WEIGHT & VOLUME OK, STRUCTURAL ATTACHMENTS ACCESSIBLE	6	5	11	79%
2. FLTS COMPATIBLE WITH OK RMS MOBILITY & NO EVA	1	3	4	29%
3. FLTS WITH ROOM IN AFT PAYLOAD BAY	4	2	6	43%
4. FLTS WITH AFT PAYLOAD BAY ROOM & OK RMS MOBILITY	2	–	2	14%

GRUMMAN

1230-038B

SPACE FABRICATION DEVELOPMENT PROGRAM

The facing page outlines a program for the development of beam builder technology that culminates in a high confidence, high reliability production beam builder in space in 10 years.

The first cross hatched entry in the chart represents this definition study. The second and third cross hatched entries represent those activities which have been included in the cost estimates of this study. Two other activities which have been dealt with in this study are necessary pre-requisits of a CBCF flight experiment. These are:

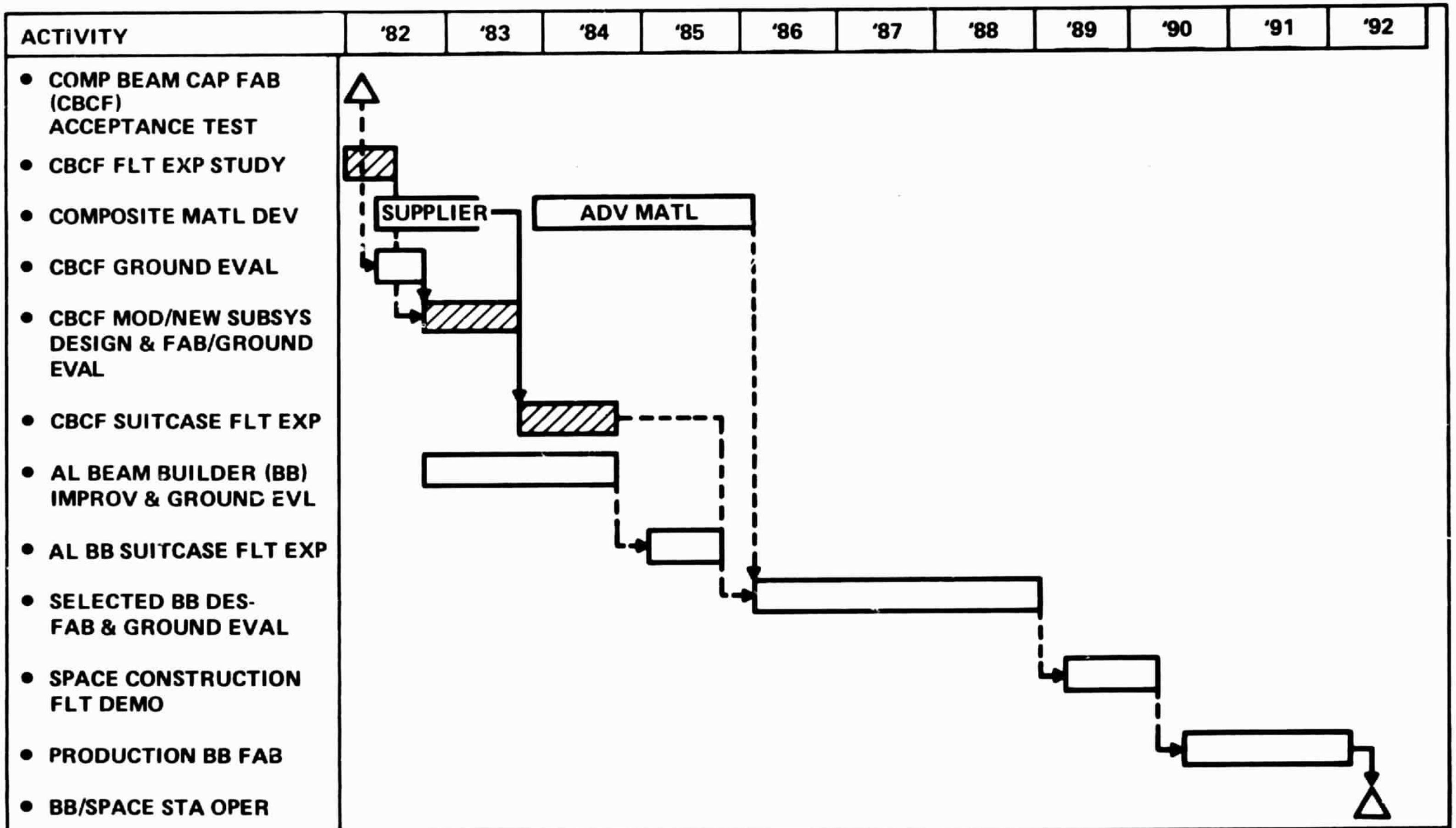
1) Development of a composite material manufacturing capability which satisfies the needs of space fabrication: material in continuous lengths of narrow strips (e.g., 6 inches wide) suitable for storage wrapped on drums
2) A ground evaluation of the various process parameters of composite beam cap fabrication. Before a flight test version is built (which is to be a prototype of the process of production CBCF), the influence of variables like forming speed, roller die adjustments, surface temperature, etc. should be known.

In addition to composite Beam Builder technology, Aluminum Beam Builder technology needs to be developed to the point of a suitcase flight experiment. As of this date, there is no clear evidence of the superiority of all aluminum versus all composite large space structures. On the facing page, a decision between the two technologies is shown near the end of 1985.

A three year period ('86 through '88) is alloted for the design, development and ground test of the selected beam builder (BB). This lengthy time is deemed necessary for the extensive thermal vacuum testing that is necessary to provide a high reliability tool. Over the last several years, our experience in bringing a large number of commercial products to market has emphasized the indespensible nature of extensive product testing.

After a flight test of the Beam Builder, additional time (1½ years) has been provided to redesign and ground test the modifications which the flight test had shown necessary.

SPACE FABRICATION DEVELOPMENT PROGRAM



- HIGH MTBF REQUIRES SIGNIFICANT RUNNING TIME DURING DEVELOPMENT TO ELIMINATE THE LARGE NUMBER OF "UNEXPECTED" PROBLEMS THAT ARE PRESENT IN ALL COMPLEX MACHINES.

GRUMMAN

1230-026B

ROM COSTS OF A CBCF FLIGHT EXPERIMENT

A rough order of magnitude (ROM) cost estimate of the flight experiment was prepared using several different methodologies.

The general approach started with an estimate from the the RCA "Price" cost estimating system. These estimates were then modified by rough estimates of engineering manpower loading and hardware costs (when there was some basis of knowledge in similar existing hardware). The costs of operating a program management office, including engineering disciplines like reliability and produceability, which would be shared by many systems, were spread out over each system in proportion to the system's share of total costs.

The two columns on the right side of the chart explain the cost differences between this estimate and the one submitted early in this study for the "Strawman" configuration.

ROM COSTS OF A CBCF FLIGHT EXPERIMENT

- COSTS ARE IN 1982 $

	SYSTEM	COST ($1000)	CHANGE IN COST FROM "STRAWMAN" ESTIMATE ($1000)	
1	QUARTZ LAMP	120	-80	
2	ROLLING MILL	420	+90	LIGHTWEIGHT ROLLING MILL
3	CUTOFF SYSTEM	150	+30	ADDITIONAL GUILLOTINE & DEVELOPMENT
4	FASTENING SYSTEM	300*	-80	REDUCED WEIGHT; BETTER DEFINITION
5	MAGAZINE SYSTEM	150	-40	
6	THERMAL/CONTAMINATION	710	+110	CHIMNEYS → MORE ENGINEERING
7	STRUCTURE	300	-170	REDUCED WEIGHT
8	ELECTRONICS/ELECTRICAL	820	+120	ADDITIONAL COMPONENTS
9	FLIGHT SUPPORT EQUIP	140	+140	NEW SYSTEM
10	GROUND SUPPORT EQUIP	110	+110	NEW SYSTEM
11	INTEGRATION, TEST & ORBITER CHECKOUT	280	+ 50	NEW SYSTEMS AND COMPONENTS

TOTAL COST = $3.5 MILLION

*THIS PRICE ASSUMES A FULLY DEVELOPED INDUCTION FASTENING SYSTEM IS SUPPLIED AS GFE

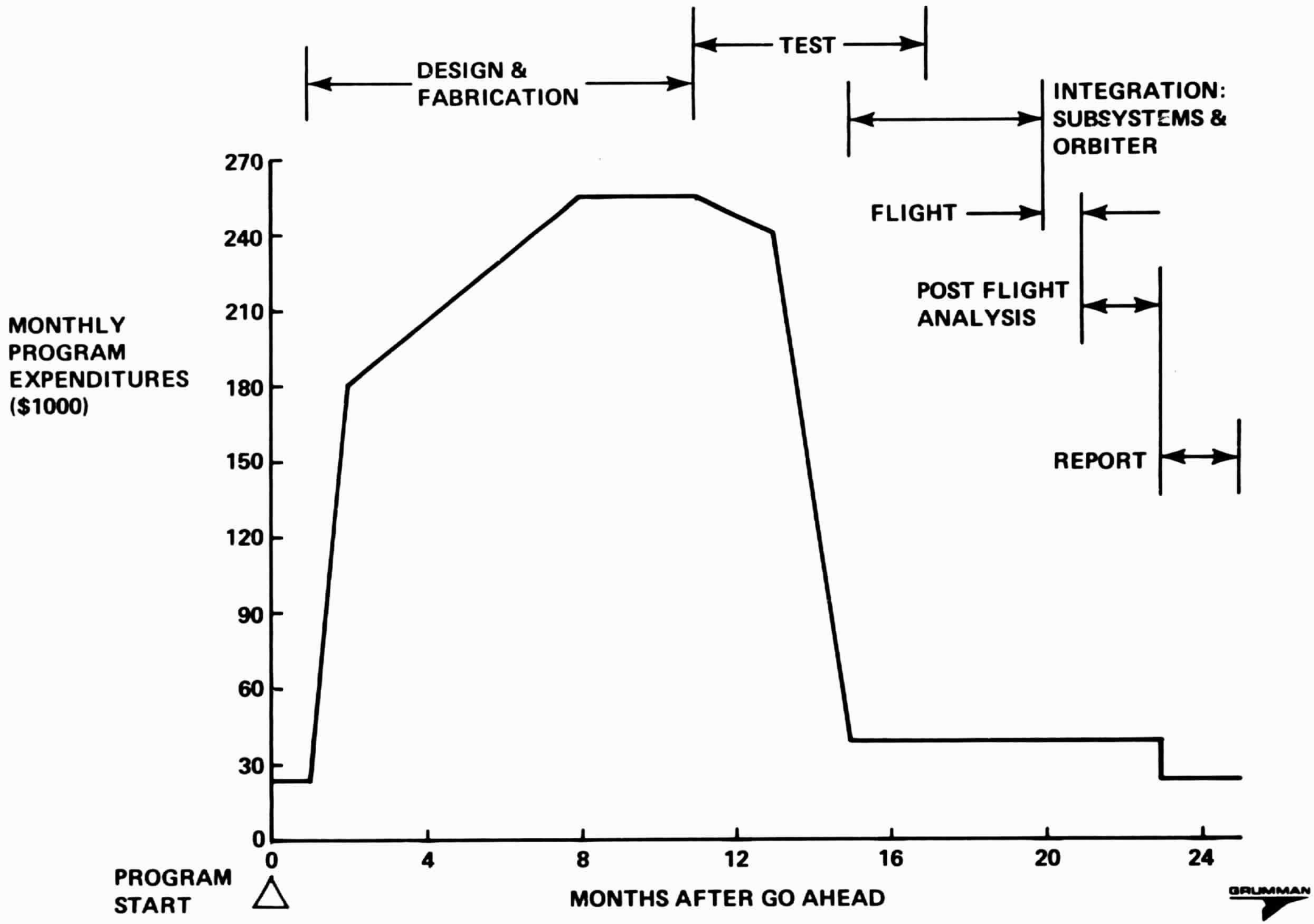
GRUMMAN

1230-034B

PROGRAM FUNDING SCHEDULE

The program funding shown on the facing page allows a 10 month period for the design and fabrication of most major systems. A test period of 6 months is shown overlapping an itegration period of 3 months. Just before this point, the CBCF Flight Experiment is ready for flight and the program is put on hold. When a suitable Orbiter flight is available, Orbiter integration tasks resume. Time is also supplied for engineering support during the flight plus 2+ months for post-flight analysis. The entire working time expected of this program is 25 months.

PROGRAM FUNDING SCHEDULE



ORIGINAL PAGE IS
OF POOR QUALITY

1230-052B

RECOMENDATIONS

The recomendations highlighted here have a major impact on the course of this flight experiment program.

Other recomendations, both explicit and implicit, on detail component design are found throughout the body of this report (including Volume 2 "Preliminary Flight Mission Plan").

RECOMMENDATIONS

- FLIGHT TEST ALL MAJOR PROCESSES REQUIRED FOR COMPOSITE BEAM BUILDER TECHNOLOGY
- USE A LIGHT WEIGHT CBCF
- VIBRATION TEST ALL COMPONENTS & THE FLIGHT EXPERIMENT ASSEMBLY
- CONDUCT EXTENSIVE THERMAL VACUUM TESTS BEFORE FLIGHT
- TRADE-OFF RMS USE VS EVA FOR CAP STOWAGE
- TILTED CONFIGURATION IS PREFERRED WITH RMS
  - TRADE-OFF TILTED VS AFT PAYLOAD BAY CONFIGURATIONS
- FUND GROUND DEVELOPMENT TEST OF CBCF PROCESS TECHNOLOGY
- FUND DEVELOPMENT OF COMPOSITE MATERIAL CONTINUOUS LENGTH MANUFACTURING TECHNOLOGY

GRUMMAN

123J-051B

CONCLUSIONS

- ALL SIGNIFICANT COMPOSITE BEAM BUILDER TECHNOLOGY CAN BE FLOWN ON A SINGLE FLIGHT
- SOME EXPERIMENT COMPONENTS AND TECHNOLOGY ARE GENERIC TO ALL SPACE FABRICATION MACHINERY
- SHORT LAUNCH ENVELOPE → 2.3 FT OF PAYLOAD BAY LENGTH
- LOW LAUNCH WEIGHT → 1800 LB
- LOW PROGRAM COST → $3.5 MILLION

1230-053B